Klohn Crippen Berger

Barkerville Gold Mines Ltd.

QR Mine Tailings Storage Facility

Background Report for Response to MEM Memorandum

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Klohn Crippen Berger

June 30, 2015

Barkerville Gold Mines Ltd.
11th Floor, 1111 Melville Street
Vancouver, British Columbia
V6E 3V6

Kevin McMurren
Mine Manager

Dear Mr. McMurren:

QR Mine Tailings Storage Facility
Background Report for Response to MEM Memorandum

We are pleased to enclose one (1) electronic copy of the Background Report for Response to MEM Memorandum for the QR Mine Tailings Storage Facility. This report provides our analysis in response to the MEM memorandum issued on February 3rd, 2015.

Should you have any questions regarding the enclosed information, please feel free to contact me

Yours truly,

KLOHN CRIPPEN BERGER LTD.

Robert Cross, M.Eng., P.Eng.
Project Manager and Geotechnical Engineer

RAC/JC/eeb

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Barkerville Gold Mines Ltd.

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CLARIFICATIONS

This report is an instrument of service of Klohn Crippen Berger Ltd. The report has been prepared for the exclusive use of Barkerville Gold Mines Limited (Client) for the specific application to the QR Tailings Storage Facility. The report's contents may not be relied upon by any other party without the express written permission of Klohn Crippen Berger. The review is based on available design and as-constructed documentation. In this report, Klohn Crippen Berger has endeavoured to comply with generally-accepted professional practice common to the local area. Klohn Crippen Berger makes no warranty, express or implied.

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1 INTRODUCTION

The Independent Expert Panel[1] (Panel) appointed by Ministry of Energy and Mines, British Columbia (MEM) released their report on the Mount Polley tailings dam failure on January 30th, 2015. Subsequent to the release of the Expert Panel report, MEM issued a memorandum on February 3rd, 2015 (MEM memorandum) to all tailings dam owners in British Columbia to undertake a specific risk assessment of their tailing dams and report the results to MEM by June 30th, 2015. A copy of the MEM memorandum is attached.

This report outlines KCB's assessment of conditions at the two dams forming the QR Mine Tailings Facility relative to the specific aspects raised by the MEM memorandum, based on a review of available documents to prepare a "summary of knowledge". This assessment has been sealed by a qualified professional engineer and complies with generally-accepted professional practice common to the local area.

The report format is based on the MEM wording and numbering system, as requested by MEM. In Sections 3 to 5 MEM items are shown in blue italicized text; KCB's response is shown in normal black text.

We consider this assessment to represent the knowledge of the facility available to KCB at the time of writing. Operating, inactive and closed facilities are subject to physical and geochemical changes over time, including ongoing construction activities. It is essential that monitoring and assessment of the facilities continue through regular surveillance, dam safety inspections, dam safety reviews and other stewardship activities.

1.1 Assessment Scope

The MEM memorandum asked that an assessment be undertaken to evaluate whether the dams may be at risk due to the following three conditions:

1. undrained shear failure of silt and clay foundation;
2. water balance adequacy; and
3. filter adequacy

KCB reviewed available historical information on foundation characterization, design, construction, and operations records for the QR Mine Tailings Storage Facility (TSF) dams to prepare responses for sub-items listed in the MEM memorandum. A register of the documents reviewed is included in Appendix II. The responses for the above three items are provided in Sections 3 to 5, respectively, following the numbering system used in the MEM memorandum.

[1] Independent Expert Engineering Investigation and Review Panel, 2015. *Report on Mount Polley Tailings Storage Facility Breach*. January 30, 2015.

2 OVERVIEW OF THE QR MINE TAILINGS STORAGE FACILITY

The QR Mine is located approximately 73 km East of Quesnel, BC, on the North Side (right bank) of the Quesnel River, approximately 3 km West (downstream) of Maud Creek. Local terrain consists of rolling hill country typical of the interior plateau of central British Columbia.

Regional bedrock geology (GSC, 1978) near to the site consists of Triassic and Jurassic basalt breccias, conglomerates, and sandstones. Bedrock at site is generally obscured (GSC, 1961) with Quarternary deposits and recent alluvium, described as consisting of till, gravel, sand, silt, and clay, with few, if any, bedrock exposures. Where exposed, the local bedrock geology (BCGS, 2007) is noted as Jurassic or Late Triassic hornblende phyric andesitic biotite flows and breccias, of the Nicola Group.

Quarternary Geology (GSC, 2015) near site consists of a till blanket (typically 2 m to 10 m thickness), with limited regions of till veneer (discontinuous, 1 m to 2 m thick), colluvial veneer (discontinuous, 1 m to 2 m thick), and landslide deposits. The till is generally described as a sandy to silty sand matrix, with clasts of a variety of grain sizes. This is further confirmed by earlier mapping (BCGS, 2003) which described the surficial geology near site as consisting of poorly sorted, moderate to well compacted, clayey to silty lodgement till, with occasional irregular sand and gravel lenses, overlying hummocky bedrock. Glaciofluvial deposits, overlaying Glaciolacustrine deposits, are noted within the adjacent Quesnel River Valley, and Maud Creek Valley. However the QR Mine Site is not located near to these deposits. The regional geology is presented in Figure 1.

The general layout of the mine is presented in Figure 2. The mine's TSF impoundment spans a 300 m wide valley north of the main mill site and consists of two zoned earth embankments, the North Dam across the northern low end of the valley, and the Cross Dyke, situated on a saddle at the south end of the valley. Historically, the TSF also had a fresh water pond for make-up water, contained by the Cross Dyke to the north, and the Fresh Water Dam to the south. The initial design indicated that at closure the Fresh Water Pond and the Tailings Pond would be joined. Following movement in the Main Zone Pit in 1997, the TSF was re-evaluated and the Site owners at the time elected to decommission the Freshwater Pond (KC, 2003).

It should be noted that prior to the decommissioning of the Fresh Water dam, the North Dam has also historically been referred to as The Tailings Dam.

The history of dam raises is presented in Table 2.1.

Table 2.1 Summary of Tailings Storage Facility Design and Construction Activities

Year	North Dam Crest El. (m)	Cross Dyke Crest El. (m)	Comment	Reference Documents
1994	1009.0	1021.0	Starter dam construction	Design: (KC, 1994a) Construction Specifications: (KC, 1994b) Construction Record: (KC, 1995a), (KC, 1996)
1995	1016.0	-	El. 1027 m ultimate crest level for new mine plan	Design: (KC, 1995b) Construction Record: (KC, 1996)
1996	1020.0	-	Dam raise	Construction Record: (KC, 1997a)
1997	1023.0	-	Dam raise	Construction Record: (KC, 1998a)
1998	-	1022.5	Dam raise	Design: (KC, 1997b), (KC, 1997c) Construction Record: (KC, 1998b)
2002	1025.0	1025.0	Dam raise	Design: (KC, 2001), (KC, 2002) Construction Record: (KC, 2003)
2006	-		Redesigned the TSF to Crest Elevation 1031 m.	Design: (KCB, 2006a) Construction Specifications: (KCB, 2006b)
2007	1028.2	1028.5	Installed a temporary spillway on the Cross Dyke	Construction Record: (KCB, 2009)
2012	1029.3	1029.3	El. 1031 m ultimate crest level for new mine plan. The Dam and Dyke were not fully raised to the design lines, due to winter conditions.	Construction Record: (KCB, 2014a)
2013	1031.0	1029.3	Removed the temporary Cross Dyke spillway. The Dam and Dyke were not fully raised to the design lines, due to winter conditions.	Construction Record: (KCB, 2014a)
2014	1031.0	1031.0	Installed the closure spillway. Completed the Cross Dyke raise to the ultimate design elevation.	Construction Record: (KCB, 2014b)

2.1 North Dam

The North Dam was constructed with a compacted glacial till core and compacted upstream and downstream rockfill shells. Downstream filters were constructed between the core and the downstream shell. Discontinuous upstream transition zones were constructed between the core and the upstream shell as the dam was raised in 1995, 1996, 1997, and 2002. The dam is primarily founded on till, with the exception of the upstream rockfill shell. The upstream shell was built by progressively pushing rockfill outwards from the starter dam in the upstream direction in order to displace weak peat and soft organic soils as the platform was advanced, and consolidate remaining peat or organic soils (KC, 1995a). The dam has generally been constructed by raising a central till core with rockfill shoulders, with the exception of the 2007 through 2013 lifts (1025 to 1031 m), where zoned till was primarily used in the construction. These upper lifts were constructed such that the centreline of the dam moved several metres upstream compared with the centreline prior to 2007.A typical section through the dam is illustrated on Figure 6.

2.2 Cross Dyke

The Cross Dyke was constructed with a silty till and clayey till core, with a till shell to the upstream and downstream. The upper portion of the upstream side of the dam consists of clayey till and sandy till, extending onto the waste rock and/or tailings as indicated on Section A of figure 8. The upstream dam face is protected by rockfill armour, overlying a transition zone (sandy till). The downstream shell is made of a sandy till, overlying a fine filter toe drain constructed from crushed waste rock. Geotextile is present along fill interfaces in the 1998 lift (1021.0 m to 1022.5 m). Because the fresh water pond was maintained at a higher elevation than the tailings pond during some of the dam's history, some of the earlier dam fill zones were designed for flow occurring from the south to the north through the Cross Dyke (KC, 1997b). Lifts have generally been constructed such that the dam centreline moves downstream of the original centreline of the dam.

3 ITEM 1: UNDRAINED SHEAR FAILURE OF SILT AND CLAY FOUNDATIONS

The surficial geology in the Mount Polley TSF area is dominated by glacially deposited quaternary deposits overlying bedrock. The Panel concluded that a glacio-lacustrine unit (GLU) interlayered between glacial till units, present at relatively shallow depths (6 m to 8 m) in the breach area, was not identified during the site characterization at Mount Polley, and was therefore unaccounted for in the design. The site investigation and laboratory testing completed by the Panel indicated the GLU unit is an overconsolidated varved silt and clay that at higher dam loads became normally consolidated with a lower undrained shear strength that was exceeded by the shear stress exerted by dam load.

a. Including a determination with respect to whether or not similar foundation conditions exist below the dams on your site.

The surface topography in the QR Mine site is primarily bedrock controlled and the surface geology is dominated by till deposits directly overlying bedrock. A regional surficial geology map of the QR Mine TSF area is shown on Figure 1.

The subsurface foundation geology indicates that the bedrock at the location of the QR Mine TSF is relatively near surface (KC, 1994a), ranging from 0.45 m to 10 m below surface, and is generally overlain by silty sand till units. The sub-surface geology above the bedrock was primarily divided into four units for foundation characterization purposes (KC, 1994a):

1. Near surface, prior to construction, occasional soft organic deposits were observed, with thicknesses ranging from 0.15 m thick up to 2.5 m thick in the valley bottom. This unit was excavated prior to placement of dam fill materials, with the exception of the ground surface under the upstream rockfill zone for the tailings dam. Within this area, the rockfill was pushed upstream to displace the underlying peat and consolidate remaining material.
2. Deposits of silty sand or sandy silt, up to 0.5 m in thickness, were encountered below the surficial organic deposits across most of the site. These soils consist of weathered, compact, non-plastic, brown silty, sandy gravel.
3. Deposits classified as silty till were encountered in all test pits across the site. The thickness of the deposits typically ranged from 2 m to more than 3.6 m. The till consists of a brown, medium dense to dense, non to low plastic, sandy gravelly silt matrix which is interspersed with cobbles up to 200 mm in size, with occasional boulders up to 900 mm observed near the base of the deposit.
4. A very dense deposit of grey, basal clay till was encountered below the silty till in most of the test pits which penetrated below the overlying silty till. The basal clay till consists of a low plastic, clayey, silty sand with some gravel interspersed in the finer-grained matrix. This basal clay till was deposited at the base of the glacial ice sheet and was therefore heavily consolidated by the weight of the ice.

Figure 3 shows the identified drill holes and test pits conducted at the site. All of the 26 drill holes for which logs contained information on the overburden soils were drilled to bedrock. The test pits were excavated to shallow depths (2 m to 5 m) with 8 of the 14 test pits terminating in the dense till. Cross-sections from 1994 design report (KC, 1994a) are shown on Figure 4 and Figure 5. These figures show the inferred surficial geology based on the test pit data. Locations of the sections are shown on Figure 2.

A review of the test pit logs indicated that the foundation predominantly consists of sandy and gravelly silt till deposits. A basal clay till deposit was observed in some locations. The available laboratory test data indicates that the basal clay till contains low plasticity clay, while the silt till contains low to intermediate plasticity clay. Fines content of the overburden soils range from 33% to 46%, and with the remaining content generally consisting of sand and gravel.

The above characterization is consistent with the surficial geology maps reviewed, prepared by the British Columbia Geological Survey, and the Geological Survey of Canada (BCGS, 2003), (BCGS, 2007), (GSC, 2015).

In conclusion, the available foundation characterization data reviewed for the QR Mine TSF did not indicate the presence of glacio-lacustrine deposits.

b. *Whether or not sufficient site investigation (drill holes, etc.) has been completed to have confidence in this determination.*

KCB believes that sufficient site investigation has been conducted to characterize foundation conditions, and develop the dam designs.

As indicated in the 2014 DSI (KCB, 2014c), the North Dam possesses adequate factors of safety against slope instability, meeting 2007 CDA recommended factors of safety. As well, the dams are not believed to be susceptible to failure or significant deformation during seismic events (KCB, 2014c).

Site investigations reviewed for the QR TSF consist of the following:

- 1988 site investigation conducted by SRK for the design of the QR TSF, including 14 test pits located within the tailings pond.
- 1990 site investigation conducted by SRK, including the advancement of 4 drill holes, and installation of piezometers in the vicinity of the TSF.
- 1994 site investigation conducted by KC in support of the design of the QR TSF. This site investigation included 4 test pits near the North Dam, 7 test pits in the tailings pond area, and 4 test pits near the Cross Dyke.
- A series of hydrogeologic and seepage investigations have also been conducted at the site including the 1995 KC site investigation, 2002 KC installation of four piezometers, 2010 Golder north dam seepage investigation, 2011 KCB seepage investigation and the 2012 KCB Phase II seepage investigation.
- Site investigations to identify sources of borrow material have also been conducted.

According to the U.S. Bureau of Reclamation "the number of drill holes required for foundation exploration of small dams should be determined by the complexity of geologic conditions but the depth of the drill holes should be greater than the height of the dam." (USBR, 1987). Although the design of the dams appears to have been primarily based on test pit data, subsequent site investigations, including drill holes through the dams, underlying soils, and the bedrock confirm assumed design foundation conditions with respect to the stability of the dams.

Although no drill holes were noted for the eastern portion of the tailings dam, TP94-11 encountered fractured bedrock at a depth of 0.45 m, and the test pit encountered refusal 1.05 m into the bedrock at a depth of 1.5 m. The test pit contained a surficial organic and silt layer, overlying silt till. TP94-9 and TP94-12 were both terminated in clay till, and TP94-10 was terminated in the silt till. Based on the relatively shallow depth of bedrock in TP94-11 and the logs, glaciolacustrine clay is not believed to be present at the North Dam.

Likewise, no drill holes were noted for the east end and the west end of the abutments of the Cross Dyke, especially for the eastern portion of the dam. However, during the 1998 raise of the Cross Dyke, the dam was extended to the east and west. A key trench was excavated at the east end of the core raise and exposed moderately fractured bedrock on the downstream face and on the downstream third of the floor of the excavation. At the west abutment, bedrock was encountered within the abutment key trench at approximate elevation 1024.5 m (KC, 1998b).

Given the site investigation conducted to date, the depth, the spatial distribution of testing is believed to be adequate for sufficient confidence in the conclusions presented above.

c. If present, whether or not the dam design properly accounts for these materials.

The foundation characterization does not indicate the presence of a glaciolacustrine silt or clay layer that could behave in an undrained manner during construction loading. Typical dam sections are presented in Figures 6, 7 and 8. Current phreatic levels in the dams are presented in Appendix III. Photos of the current site configuration, obtained from the 2014 DSI, are presented in Appendix IV.

Stability analyses conducted for the current design of the dams is believed to adequately account for the foundation materials present under the North Dam and the Cross Dyke. Although SPT and CPT data is not available, assumed soil strengths and densities used in design appear to be reasonable for the available field and laboratory test data. Based on the foundation characterization, drained foundation conditions were used to develop the initial design and subsequent redesigns for the QR TSF. The current configuration of the dams were assessed as part of the 2006 North Dam and Cross Dyke Re-Design (KCB, 2006a) and found to have adequate factors of safety under static and seismic conditions.

It should be noted that allowable seepage rates for the purpose of maintaining a water cover over the tailings are exceeded at the North Dam. Seepage is understood to occur through a fractured bedrock zone below the dam, as identified during the Phase I (KCB, 2012a) and Phase II (KCB, 2014d) investigations. A trial grouting program was undertaken to address this issue, and completion of this work is recommended (KCB, 2014c). This is not believed to be an issue from a dam physical stability perspective.

d. If any gaps have been identified, a plan and schedule for additional sub-surface investigation.

No further subsurface investigation is recommended at this time to address the foundation soils. As previously recommended in the 2014 DSI, ongoing monitoring of the facility is recommended.

4 ITEM 2: WATER BALANCE

At the time of August 4, 2014 breach, the Mount Polley TSF was holding surplus water. Surplus water was defined by the Panel as the volume of water that accumulates in the TSF over time because the inflow exceeds the outflow capacity. The inflow could be from mine operations, a climatic event or a combination of both. The Panel concluded that excess water accumulated in the TSF did not trigger the failure but did contribute to a more severe downstream adverse impact.

a. Including the total volume of surplus mine site water (if any) stored in the tailings storage facility.

The QR Mine TSF has not been filled to capacity and no further tailings are planned for deposition in the facility. The facility does not presently receive or hold water from mining operations. The current sources of inflow for the TSF comprise precipitation on the tailings surface and surface runoff from the natural surrounding catchment. The following provides additional information about water management within the facility:

- The facility is operated under Permit 12601, originally issued March 3, 1994 and revised July 11, 2012. The permit stipulates that discharge into the TSF is not authorized until plans to mitigate seepage losses from the tailings impoundment have been developed.
- Diversion ditches are currently being maintained along the east and west sides of the TSF to collect runoff and divert water around the TSF. Provided the ditches are properly maintained and cleared regularly, they will continue to divert water around the TSF.
- The only other source of outflow is via seepage and evaporation. Both the North Dam and Cross Dyke experience seepage; however, seepage is collected in a seepage collection pond and pumped back to the impoundment (KCB, 2014c).

According to the current Annual Reclamation Review Report provided by BGM (BGM, 2014a), water from the TSF is pumped to the mill as required to operate the mill. Reclaim water from the TSF makes up the majority of the water required to operate the mill (85%), with the remaining make-up water (15%) pumped from the Main Zone Pit. Mill reclaim rates provided by BGM for July 2014 to September 2014 indicate an average monthly reclaim rate of 14,000 m^3, of which roughly 11,900 m^3 would have been reclaimed from the TSF. We understand that this balance between water sourced from the Main Zone Pit and TSF is modified as needed by site requirements, and the reported balance noted in the Annual Reclamation Review Report may no longer be current.

In the event of an extreme flood event, excess flows will be discharged via the open-channel closure spillway.

b. The volume of surplus mine water that has been added to the facility over each of the past five years.

The water level has fluctuated over the past five years, but, in general, has increased approximately 2 m. The water level observed during the 2010 Annual Inspection was 1025.5 m (KCB, 2011) and was 1027.5 m during the most recent 2014 Dam Safety Inspection (DSI) (KCB, 2014a). Based on a bathymetry survey carried out in 2012, the 2 m increase in pond level amounts to approximately 314,000 m^3 of additional water storage at the facility over the past 5 years.

The volume of free water in the TSF as of November, 2014 was approximately 505,000 m^3. Approximate volumes over the past five years are presented in Table 4.1.

Table 4.1 Summary of Observed Water Level in QR Mine TSF (Last 5 Years)

Year	Water Level (m) (1)	Approximate Volume (m^3)
2010	1025.5	190,000
2011	1026.7	360,000
2012	1026.7	365,000
2013	1026.9	400,000
2014	1027.5	505,000

Note: (1) Water levels have been taken from available reports and represent a snapshot only. Seasonal water level fluctuations have been observed at the site.

c. Any plans that are in place or that are under development to release surplus mine water to the environment.

Tailings deposition into the QR TSF has ceased and the facility is primarily used as a source of water for mill reclaim. Other than continuing to supply the mill with reclaim water, there is no plan either in place or under development to release water to the environment. However plans are being developed to transfer some water from the QR TSF to the Main Zone Pit. These plans are preliminary at this time, and, once developed, would require approval by the Ministry of the Environment.

Based on the current TSF configuration, in the event of an extreme flood, the closure spillway will provide outflow capacity to release the additional inflow. The Closure Spillway, constructed in 2014, was sized to convey a PMF event without diversions ditches operating.

Based on the bathymetry survey carried out in 2012, there is approximately 1.5 m of pond level available between the spillway and the most recent 2014 DSI observed water level of 1027.5 m. This equates to approximately 285,000 m^3 of available storage; enough to store a 1:100-year rain plus snowmelt induced flood with a 30 day duration, without discharge from the spillway (assuming seepage and mill reclaim is negligible and the diversions are maintained).

Since initial construction of the TSF at QR Mine, seepage has been observed at the downstream toe of the North Dam, and seepage, or natural spring flows, have been observed at the downstream toe of the Cross Dyke. Seepage rates for the North Dam have previously been estimated to be around 5 L/s, and the flows (seepage or natural spring flows) observed at the Cross Dyke have been previously estimated to be around 1 L/s. Seepage, where observed, likely occurs through a fractured upper zone of the bedrock underlying the dam foundations. The flows are currently collected and returned to the TSF, and are not released.

While seepage is currently collected, when the seepage return pumps are removed at closure the seepage has been calculated to exceed the maximum rate allowable to provide sufficient water cover over the impounded tailings after closure (KCB, 2010). The water cover is required to maintain saturation of the tailings to prevent oxidation and, ultimately, acid generation. There is, therefore, expected to be in a net deficit and water inflows will likely be required from additional sources (e.g., removing diversion or diverting additional water into the facility) to maintain a water cover. A grouting trial was completed (KCB, 2014d) to evaluate the feasibility and best method of injection grouting the fractured bedrock zone as a seepage mitigation measure. Closure measures are still being evaluated.

d. Recommended beach width(s) and the ability of the mine to maintain these widths.

In the context of this report, beach width refers to the extent of the tailings that deposit above water upstream of the tailings dam. Tailings are no longer being deposited in TSF. When deposition was ongoing, tailings were deposited sub-aqueously by gravity feed and spigotting on a continuous basis (KCB, 2014b). Tailings discharge points were moved around different locations of the pond to achieve as flat a surface below the water as possible, and to aid in reducing the seepage flow in order to maintain the 1 m water cover over PAG material specified for final reclamation (KCB, 2014c). Photos from the 2014 DSI show the beach is fully submerged and water is against the upstream face of the dams.

The QR TSF is confined by the Cross Dyke which is generally a downstream configuration, and the North Dam which is a centreline configuration with the exception of the most recent upstream lifts. The upstream rockfill shell extends over 90 m to the upstream of the dam core zone. The stability of the two dams does not rely on a tailings beach, and no design beach width was specified for either the North Dam or the Cross Dyke.

e. The ability of the TSF embankments to undergo deformations without the release of water (i.e., the adequacy of the recommended beach width).

Static loading due to dam raising is complete and the main source of additional potential deformation for the QR TSF is possible earthquake loading. The calculated seismic deformations (horizontal and vertical) for the QR TSF can be accommodated by the 2.0 m of available normal freeboard (i.e., between the spillway invert and the dam crest), and the embankment shell, to prevent the release of water or tailings.

Based on the 2014 DSI, there is 3.5 m of freeboard from the current pond elevation to dam crest elevation. Based on design calculations from the spillway, the pool rise associated with routing the design event is approximately 0.6 m. The minimum freeboard available (i.e., between the highest routed water level and the dam crest) is estimated to be 1.4 m, the normal freeboard available (i.e., between the spillway invert and the dam crest) is estimated to be 2.0 m.

The main potential source of additional deformation for QR TSF dams is possible earthquake loading. KC (1994a) reviewed regional historical earthquakes, as well as seismic studies by others, and noted that the Maximum Credible Earthquake expected at the site is estimated to have a peak ground acceleration of 0.17 g, with the maximum magnitude earthquake recorded for the region being a M5.4 earthquake. Swaisgood (2013) and Hynes-Griffin and Franklin (1984) methods were used to estimate potential vertical and lateral seismic deformations of the dams, respectively. Based on the available background information regarding expected design yield accelerations for the dams, the estimated seismic deformations can be accommodated by the available normal freeboard of 2.0 m at either dam, to prevent the release of any water or tailings due to embankment deformation.

f. Provisions and contingencies that are in place to account for wet years.

A water balance review was undertaken in 2012 as part of the Dam Raise detail design (KCB, 2012b). The water balance for a 'wet year', assumed to be a 100-year return, was checked for the current status of the TSF. The water balance calculation indicates:

- That 50% of total inflows would be lost through evaporation.
- Release via seepage was assumed to be zero as it is collected and returned to the pond.
- The mill reclaim rates provided by BGM, and assumed to be typical rates, are sufficient to keep the pond in a neutral state and the expected raise in pond water level would be negligible.
- The total annual inflow into the impoundment (runoff and precipitation) during a wet year is estimated to be 210,000 m^3, compared to an average year of 158,000 m^3.
- Even if this yearly volume were to be stored in the impoundment without evaporation or mill reclaim, it would result in a 1.1 m rise in the pond level, which remains 0.5 m below the invert of the spillway.

The Operation, Maintenance and Surveillance Manual (BGM, 2014b), states that the level of the tailings pond should not exceed an elevation of 1028.3 m. If this level is exceeded, the Mine Manager will notify the facility designer (KCB) for appropriate action and ongoing monitoring frequency. This would provide approximately 145,000 m^3 of additional water storage at the current 2014 DSI water level of 1027.5 m.

g. If any gaps have been identified, a plan and schedule for addressing these issues.

1. The Operation, Maintenance and Surveillance (OMS) Manual was updated in 2014 and is currently undergoing an additional update to support operations, maintenance and surveillance of the North Dam and Cross Dyke (BGM, 2014b). Once long-term planning regarding the facility is complete the water balance should be revised to reflect planned conditions.
2. During the 2014 Dam Safety Inspection (KCB, 2014c) it was recommended that a trial grouting program be conducted and an overall seepage mitigation plan be developed. It was recommended that this be done by the end of 2015.

5 ITEM 3: FILTER ADEQUACY

During the post-breach site investigations of Mount Polley TSF, the Panel found evidence of a cavity in the left abutment of the breach that was the possible result of internal erosion. Furthermore, the Panel noted that the filter and transition zone was thin and that the as-built drawings indicated departure from intended design, and that much of the as-placed filter material failed to meet the applicable filter criteria and requirements for internal stability. While the Panel did not find any evidence that the Mount Polley failure was caused by piping and/or cracking due to filter inadequacy, it did note that piping and cracking of the core of an earth-rockfill dam can lead to internal erosion and ultimately loss of containment and is one of the most common causes of failure of earth dams.

a. Including the beach width and filter specifications necessary to prevent potential piping.

The QR TSF is confined by the Cross Dyke, which generally has a downstream configuration, and the North Dam, which has a centreline configuration, with the exception of the most recent upstream lifts. The upstream rockfill shell of the North Dam extends over 90 m to the upstream of the dam core zone.

The design of the TSF relies on low permeability dam cores of compacted till to restrict seepage and maintain a water cover over the tailings and waste rock (KC, 1994a). The stability of the dams does not rely on a tailings beach, and no design beach width was specified for either the North Dam or the Cross Dyke.

Seepage rates at the North Dam have been noted to be higher than preferred for the purposes of maintaining adequate water cover over the tailings within the TSF. This seepage appears to generally be through a fractured bedrock zone below the dam. Grouting of this bedrock zone has been partially completed, and completion of the grouting program is recommended (KCB, 2014c). Seepage is collected at the toe of the North Dam and pumped back into the facility and estimated at approximately 5 L/s.

At the Cross Dyke seepage would be collected at the toe and routed to the Main Zone Pit. Limited flow was observed along the right (west) abutment toe drain.This flow was noted as approximately 2 L/s, however it is not certain whether the flow consists of seepage through the dam or natural spring flow. No visible seeps were observed on the east abutment (KCB, 2014c).

The original design for the filter zones was developed based on the following design criteria for the retention of base soils:

- D15 of the filter / d85 of the protected soil < 5, where d85 of the base soil is based on the finer fraction passing the No. 4 sieve.
- Maximum particle size of the filter D100 = 75 mm.

Notes on the design filter zones for the North Dam and Cross Dyke follow.

North Dam

- The North Dam is generally broken into 8 major fill zones, as shown on Figure 6. However, seepage flow is expected to generally occur below elevation 1,025 m in the dam and, as such, only fill zones below elevation 1,025 m (corresponding to the 2002 construction period and earlier) were assessed for filter compatibility.
- Below elevation 1,025 m, there are 6 zones consisting of: the Upstream Shell, a Till Transition Zone, a Till Core, a Fine Filter, a Coarse Filter, and the Downstream Shell.
- Design envelopes for the filter zones below elevation 1,025 m are presented in Figure 9.
- The width of the dam core was designed to be at least 10 m, providing a minimum ratio of core width to hydrostatic head of approximately 0.67 (KC, 1997c). The width of the dam was designed to be at least 50% of the reservoir head against the core. This is twice the ratio of 0.25 to 0.3 often used for water storage dams.
- The Till Transition Zone comprises a silty sandy till to protect the upstream side of the core and act as a crack filler in the event of a crack in the core.
- The design for the filter zones were developed based on engineering standards at the time. As filter design recommendations have changed since the development of the design recommendations for the filter gradations at the QR Mine, KCB has compared the available design information to current design recommendations as per the US Army Corps of Engineers (2004), and Kenney and Lau (1986). Assessment of the filter designs compared to modern design recommendations is presented in Appendix V and summarized in the table below.

Table 5.1 Summary of Design Gradations Compared to Modern Design Criteria

Year[(1)]	Base Soil	Filter Zone	USACE (2004)[(2)]					Kennie and Lau [(3)](1986)
			% passing 75 um	Max D15	Min D15	D90	D100	H<F For F<20%
1994	Till Core	Fine Filter	Pass	Fail	Pass	Fail	Pass	Fail
	Fine Filter	Coarse Filter	--	--	--	--	--	--
1995	Till Core[(4)]	Fine Filter	Pass	Fail	Pass	Fail	Pass	Fail
	Fine Filter	Coarse Filter	--	Fail	Pass	Fail	Fail	Fail

[(1)] The year corresponds to the date of the specifications.
[(2)] USACE (2004) criteria were calculated based on the finest gradation of the protected material, after regarding to a maximum grain size of 4.75 mm.
[(3)] Kenney and Lau (1986) method was applied for a widely graded filter. Parameter H corresponds to the mass fraction of the filter particles whose diameter ranges between D and 4D. F corresponds to the mass fraction of particles whose diameter is smaller than diameter D.
[(4)] Only filter gradations were modified in 1995. 1995 Re-design of filters were compared to the 1994 construction specifications for the till core.

In general, although the filters were designed according to generally accepted standards typical at the time of design development, the design of the filter zones for the North Dam does not meet modern filter design criteria. The filter designs meet permeability criteria, but do not meet filter retention criteria (USACE, 2004), and also do not meet gradation requirements to prevent segregation of filters during construction (USACE, 2004). The design gradations may also be susceptible to internal erosion (Kenny and Lau, 1986).

Cross Dyke

- The Cross Dyke is generally broken in to 6 major fill zones: the Silty Till Core, Clay Core, the Upstream Silty Sand Shell, the Downstream Silty Sand Shell, and the Fine Filter Toe Drain. These zones are shown on Figure 8.
- Similar to the North Dam, seepage through the structure is generally expected to occur below elevation 1,025 m in the dam.
- Design envelopes for the filter zones below elevation 1,025 m are presented in Figure 10. The design for the filter zones were developed based on engineering standards at the time. As filter design recommendations have changed since the development of the design recommendations for the filter gradations at the QR Mine, KCB has compared the available design information to current design recommendations as per the US Army Corps of Engineers (2004), and Kenney and Lau (1986). Assessment of the filter designs compared to modern design recommendations is presented in Appendix V and summarized in the table below.

Table 5.2 Summary of Design Gradations Compared to Modern Design Criteria

Year(1)	Base Soil	Filter Zone	USACE (2004)(2)					Kennie and Lau (3) (1986)
			% passing 75 um	Max D15	Min D15	D90	D100	H<F For F<20%
2001	Till Core(4)	Fine Filter Toe Drain	Pass	Fail	Pass	Fail	Pass	Fail
2001	Till Foundation (5)	Fine Filter Toe Drain	Pass	Fail	Pass	Fail	Pass	Fail
2006	Down-stream Shell	Fine Filter Toe Drain	Pass	Pass	Pass	Fail	Pass	Fail
2006	Till Foundation (5)	Fine Filter Toe Drain	Pass	Pass	Pass	Fail	Pass	Fail

(1) The year corresponds to the date of the specifications.
(2) USACE (2004) criteria were calculated based on the finest gradation of the protected material, after regarding to a maximum grain size of 4.75 mm.
(3) Kenney and Lau (1986) method was applied for a widely graded filter. Parameter H corresponds to the mass fraction of the filter particles whose diameter ranges between D and 4D. F corresponds to the mass fraction of particles whose diameter is smaller than diameter D.
(4) Although the fine filter toe drain specification was produced in 2001, the design of the till core is based on the 1994 construction specifications.
(5) Till foundation gradation based on the gradation of basal clay sample from TP94-17 at a depth of 3.3 m (KL, 1994).

In general, although the filters were designed according to generally accepted standards typical at the time of design development, the design of the filter zones for the Cross Dyke does not meet modern filter design criteria. The filter designs meet permeability criteria, but do not meet filter retention criteria (USACE, 2004), and also do not meet gradation requirements to prevent segregation of filters during construction (USACE, 2004). The design gradations may also be susceptible to internal erosion (Kenny and Lau, 1986).

b. Whether or not the filter has been constructed in accordance with the design.

Generally, where available, the as-built records for both the North Dam and Cross Dyke construction materials adhere to the design specifications. Some limited exceptions are presented below.

North Dam

As noted, the as-built records of the North Dam construction materials generally adhere to the design specifications, with the following exceptions (KC, 1995a), (KC, 1996), (KC, 1997a):

- Most samples of the Till Core were within the specified limits, with some limited samples somewhat finer or coarser than the specified limits. During construction, Till Core materials varied by borrow source from a silty till to a clayey till, with fines content ranging from 8% to 58%.
- The Fine Filter samples generally plotted near or along the coarse design limit. A limited number of samples were coarser than specified.
- One Coarse Filter sample was coarser than the specified design limits.

The available as-built grain size data compared to the design at the time is summarized in Table 5.3 and 5.4. Table 5.3 summarizes the filter compatibility of the Fine Filter with respect to the Till Core. Table 5.4 summarizes the filter compatibility of the Fine Filter with respect to the Coarse Filter. As the zones were placed in phases over a number of project years, and as material supply varied from year to year, the available information has been summarized by both year and dam fill zone. The tested gradations of the fine and coarse filter met the original design criteria of $D15/d85<5$.

Filter placement and compaction in 1995, from elevation 1,013 m to 1,016 m, was monitored by Kinross. However, two test pits were later excavated by KC in these filter zones, which verified the thickness of the fine filter zone and confirmed that excessive segregation of the filter material had not occurred during placement (KC, 1996).

Table 5.3 As-Built Fine Filter Information Compared to Design – North Dam

Year	Crest Elevation	Till Core		Fine Filter		Comparison of As-Built to Design (Till / Fine Filter)	
		D100 (mm)	d85[1] (mm)	D100 (mm)	D15 (mm)	D15 / d85	Less Than Design Limit of 5
1994	1009	76	2-3	No filter construction undertaken in 1994.		< 3[2]	Yes
1995	1013 (Phase I)	101	3-4	76	0.9-6	< 2	Yes
1996	1020	76	0.7-2	76	0.6-2	< 3	Yes
1997	1023	No as-built information available.		No as-built information available.		--	
2002	1025.0 (west end of dam)	No as-built information available.		No filter construction undertaken in 2002.		--	

[1] This d85 (mm) is based on the particle size gradation after regrading to a maximum grain size of 4.75 mm.
[2] The 1994 Till core is filtered by the Fine Filter constructed in 1995. As such, as-built gradations for the 1994 Till Core were compared to the as-built 1995 Fine Filter gradations.

Table 5.4 As-Built Coarse Filter Information Compared to Design – North Dam

Year	Crest Elevation	Fine Filter		Coarse Filter		Comparison of As-Built to Design (Fine Filter / Coarse Filter)	
		D100 (mm)	d85 (mm)	D100 (mm)	D15 (mm)	D15 / d85	Less Than Design Limit of 5
1995	1013 (Phase I)	76	33-53	203	4-25	< 1	No
1996	1020	76	37-58	No as-built information available.		--	

KCB has also compared the relevant as-built design information to current design recommendations as per the US Army Corps of Engineers (2004), Kenney and Lau (1986), and the recommendations of Foster and Fell (2001). Assessment of the as-built filters compared to modern design recommendations is presented in Appendix VI and summarized in the table below.

Table 5.5 Comparison of As-Built Filter Gradations to Modern Design Criteria - North Dam

Year[(1)]	Base Soil	Filter Zone	USACE (2004)[(2)]					Foster and Fell (2001)[(3)]			Kenney and Lau (1986)[(4)]
			% passing 75 um	Max D15	Min D15	D90	D100	NE[(5)]	EE[(6)]	CE[(7)]	H<F For F<20%
1994	Till Core	Fine Filter[(8)]	Pass	Pass	Pass	Fail	Fail	Fail	Pass	Pass	--
1995	Till Core	Fine Filter	Pass	Pass	Pass	Fail	Fail	Fail	Pass	Pass	Fail
1995	Fine Filter	Coarse Filter	Pass	Fail	Pass	Fail	Fail	Fail	Pass	Pass	Fail
1996	Till Core	Fine Filter	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Pass	Pass
1997	Till Core	Fine Filter	No as-built information available.								
2002	Till Core	Fine Filter	No filter construction undertaken in 2002.								

(1) The year corresponds to the year that the dam zone that is being filtered ("base soil") was constructed.
(2) USACE (2004) criteria were calculated based on the finest gradation of the protected material, after regarding to a maximum grain size of 4.75 mm.
(3) Application of the Foster and Fell criteria may not be applicable as both the filter and base soil are susceptible to segregation (as per USACE, 2004) and internal instability (as per Kenney and Lau, 1986).
(4) Kenney and Lau (1986) method was applied for a widely graded filter.
(5) NE corresponds to the criteria for no erosion, as outlined Foster and Fell (2001).
(6) EE corresponds to the criteria for excessive erosion, as outlined Foster and Fell (2001).
(7) CE corresponds to the criteria for continuous erosion, as outlined Foster and Fell (2001).
(8) Fine filter zone protecting the 1994 till core was constructed in 1995.

Based on the assessment conducted, the available gradations for the as-constructed dam materials indicate that permeability design criteria (USACE, 2004) are met. Some of the filter zones do not meet soil retention criteria (USACE, 2004) and most do not meet maximum particle size criterion (USACE, 2004). The assessment also indicates that the as-constructed filters may be susceptible to internal erosion (Kenney and Lau, 1986), and gradation requirements to prevent segregation during construction are generally not met (USACE, 2004).

Although the soils do not meet the criteria outlined above, on the basis of the generally clear seepage, there has been no evidence of widespread migration of the base soil or the impounded tailings through the North Dam. The 2014 DSI also notes that "if the internal filters do not perform as designed, tailings fines that migrated through the dam would not result in a structural failure of the dam given the high shear strength of the coarse rockfill. Migration of tailings into the downstream shell could impact environmental containment performance but there is no evidence this has occurred" (KCB, 2014)

Cross Dyke

The as-built records of the Cross Dyke construction materials generally adhere to the design specifications, with the exception of the following:

- The Blanket Drain constructed in 2012-2013 is coarser than the design limits specified, which were the same gradation limits as specified for the Fine Filter Toe Drain (KCB, 2014a). Based on the gradation of this material, segregation of the material could potentially have occurred during construction. The construction records indicate that filter compatibility of the Blanket Drain with the adjacent Sandy Till Downstream Shell was found acceptable according to the following criteria (KCB, 2014a):
  - Piping criteria was satisfied (D15/d85 < 5);
  - Permeability criteria was met (D15/d15>5);
  - Collected samples yielded average fines content of 3.4% which is less than the 5% specified in the filter design criteria; and
  - The fine filter material was well compacted.

The available as-built grain size data is summarized in Table 5.6 for the Fine Filter Zone, and Table 5.7 for the Blanket Drain.

Table 5.6 As-Built Toe Drain Filter Information Compared to Design – Cross Dyke

Year	Crest Elevation	Protected Material	Gradation of Protected Material		Toe Drain Filter		Comparison of As-Built to Design (Till Core / Toe Drain)	
			D100 (mm)	d85[1] (mm)	D100 (mm)	D15 (mm)	D15 / d85	Less Than Design Limit of 5
1994	1021	Till Core	33	2-3	Filter constructed in 2002.		< 1	Yes
2002	1022.5	Till Core	76	1-2	75	0.6-2	< 2	Yes
2002	1022.5	Till Foundation[2]	38	0.85	75	0.6-2	< 4	Yes

(1) d85 (mm) is based on the particle size gradation after regrading to a maximum grain size of 4.75 mm.
(2) Till foundation gradation based on the gradation of basal clay sample from TP94-17 at a depth of 3.3 m (KL, 1994).

Table 5.7 As-Built Blanket Drain Filter Information Compared to Design – Cross Dyke

Year	Crest Elevation	Protected Material	Gradation of Protected Material		Blanket Drain		Comparison of As-Built to Design (Downstream Shell / Blanket Drain)	
			D100 (mm)	d85[2] (mm)	D100 (mm)	D15 (mm)	D15 / d85	Less Than Design Limit of 5
2012-2013	1029.3	Downstream Shell	76	1-3	150	2-4[3]	< 4	Yes
2012-2013	1029.3	Till Foundation	38	0.85	150	2-4[3]	< 5	Yes

(1) The filter criteria check was between the downstream shell and the blanket drain to the downstream.
(2) d85 (mm) is based on the particle size gradation after regrading to a maximum grain size of 4.75 mm.
(3) Till foundation gradation based on the gradation of basal clay sample from TP94-17 at a depth of 3.3 m (KL, 1994).

KCB has also compared the relevant as-built design information to current design recommendations as per the US Army Corps of Engineers (2004), Kenney and Lau (1986), and the recommendations of Foster and Fell (2001). Assessment of the as-built filters compared to modern design recommendations is presented in Appendix VI and summarized in the table below.

Table 5.8 Comparison of As-Built Filter Gradations to Modern Design Criteria – Cross Dyke

Year(1)	Base Soil	Filter Zone	USACE (2004)(2)					Foster and Fell (2001)(3)			Kenney and Lau (1986)(4)
			% passing 75 um	Max D15	Min D15	D90	D100	NE(5)	EE(6)	CE(7)	H<F For F<20%
1994	Till Core	Fine Filter Toe Drain(5)	Pass	Pass	Pass	Pass	Pass	Fail	Pass	Pass	--
2002	Till Core	Fine Filter Toe Drain	Pass	Fail	Pass	Pass	Pass	Fail	Fail	Pass	Fail
2002	Till Foundation	Fine Filter Toe Drain	Pass	Fail	Pass	Pass	Pass	Fail	Pass	Pass	Fail
2012 - 2013	Downstream Shell	Blanket Drain(8)	--	Fail	Pass	Fail	Pass	Fail	Fail	Pass	Fail
2012 - 2013	Till Foundation	Blanket Drain(8)	Pass	Fail	Pass	Fail	Pass	Fail	Fail	Pass	Fail

(1) The year corresponds to the year that the dam zone that is being filtered (“base soil”) was constructed.
(2) USACE (2004) criteria were calculated based on the finest gradation of the protected material, after regarding to a maximum grain size of 4.75 mm.
(3) Application of the Foster and Fell criteria may not be applicable as both the filter and base soil are susceptible to segregation (as per USACE, 2004) and internal instability (as per Kenney and Lau, 1986).
(4) Kenney and Lau (1986) method was applied for a widely graded filter.
(5) The fine filter toe drain filtering the 1994 till core zone was constructed in 2002.
(5) NE corresponds to the criteria for no erosion, as outlined Foster and Fell (2001).
(6) EE corresponds to the criteria for excessive erosion, as outlined Foster and Fell (2001).
(7) CE corresponds to the criteria for continuous erosion, as outlined Foster and Fell (2001).
(8) 2002 filter criteria check was between the downstream shell and the fine filter toe drain. The 2012-2013 filter criteria check was between the downstream shell and the blanket drain to the downstream.

The assessment conducted on the available gradations for the as-constructed dam materials for the Cross Dyke indicated the following:

- The fine filter toe drain meets gradation requirements for permeability, maximum gradation size, and prevention of segregation during construction (USACE, 2004). It does not meet particle retention criteria for all of the assessed zones (USACE, 2004). This filter zone may also be susceptible to internal erosion (Kennie and Lau, 1986).
- The blanket drain does not meet gradation requirements for permeability, particle retention, and prevention of segregation during construction (USACE, 2004). This filter zone may also be susceptible to internal erosion (Kenney and Lau, 1986).

Although the soils do not meet the criteria outlined above, on the basis of the generally clear seepage, there has been no evidence of widespread migration of the base soil or the impounded tailings through the Cross Dyke.

c. If any gaps have been identified, a plan and schedule for addressing these issues.

As noted, gaps exist within the as-built records of the dam fill zones. In addition, the design and the as-built gradations of the filters do not meet one or more of the assessed filter criteria (USACE, 2004), Kenney and Lau (1986), and Foster and Fell (2001).

No immediate further assessment of the filters is deemed necessary in order to evaluate filter adequacy, based on the following:

- No documentation or observations of local deformations / washouts, voids, or piping are indicated.
- Filter performance has been demonstrated by clear seepage and retention of tailings in the impoundment.
- The low permeability core zones are wide in relation to the dam height and the upstream transition zones offer additional protection.

There is, however, a requirement for ongoing monitoring of the seepage to check for continuing filter adequacy, based upon the following:

- The gradations of the filter and base soils are such that they are susceptible to segregation and internal stability, and are within the range of gradations where filter performance has often been poor (Foster and Fell, 2001).
- The facility continues to retain water, including water ponded directly against the upstream face of the dams.

The above requirement for continued monitoring of the performance of the dam was also recommended in the 2014 DSI (KCB, 2014c). As part of this assessment, the following specific recommendation is provided with respect to filter adequacy:

- Given the potential for filter inadequacy, seepage should be monitored for both dams on at least a monthly basis. The seepage should also be monitored for suspended solids.

6 SUMMARY OF GAPS AND SCHEDULE TO ADDRESS

MEM Letter		Schedule to Address
Item No.	Gap Identified	
1.	**Undrained shear failure of silt and clay foundation**	
	▪ No further subsurface investigation is recommended at this time to address the foundation soils. Ongoing monitoring of the facility is recommended.	
2.	**Water balance adequacy**	
	▪ Water balance should be revised to reflect planned conditions. ▪ Trial grouting program should be conducted and an overall seepage mitigation plan should be developed.	▪ To be completed once long-term planning regarding the facility is complete. ▪ To be completed once long-term planning regarding the facility is complete.
3.	**Filter adequacy**	
	▪ The need for slope monitoring equipment should be assessed. ▪ Continued monitoring of seepage from the facility is recommended, including for presence of suspended solids.	▪ Slope monitoring needs to be developed during 2015 DSI (expected by end of Q3 2015). ▪ Ongoing monitoring to continue.

In addition to the three major scope items summarized in the table above, the MEM also requested the following information in their memorandum:

- *Is your mine implementing the "Toward Sustainable Mining" initiative of the Mining Association of Canada? Are there any plans to do so?*
- *Does your mine have an Independent Tailings Dam Review Board (ITRB) in place? Is one planned?*

These items have not been addressed by KCB; further information will be provided by BGM.

7 CLOSING

We would like to thank you for the opportunity to work on this assignment. Should you have any questions, or further needs, please do not hesitate to contact either of the undersigned.

Yours truly,

KLOHN CRIPPEN BERGER LTD.

PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
R. A. CROSS
35570

June 30, 2015

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MO/JC/RAC/eeb

Appendix:

Figures
Appendix I – MEM Letter to Barkerville Gold Mines Ltd.
Appendix II – Summary of Relevant Reports
Appendix III – 2014 Piezometer Readings
Appendix IV – 2014 Site Photos
Appendix V – Design Filter Assessment
Attachment VI – As-Built Filter Assessment

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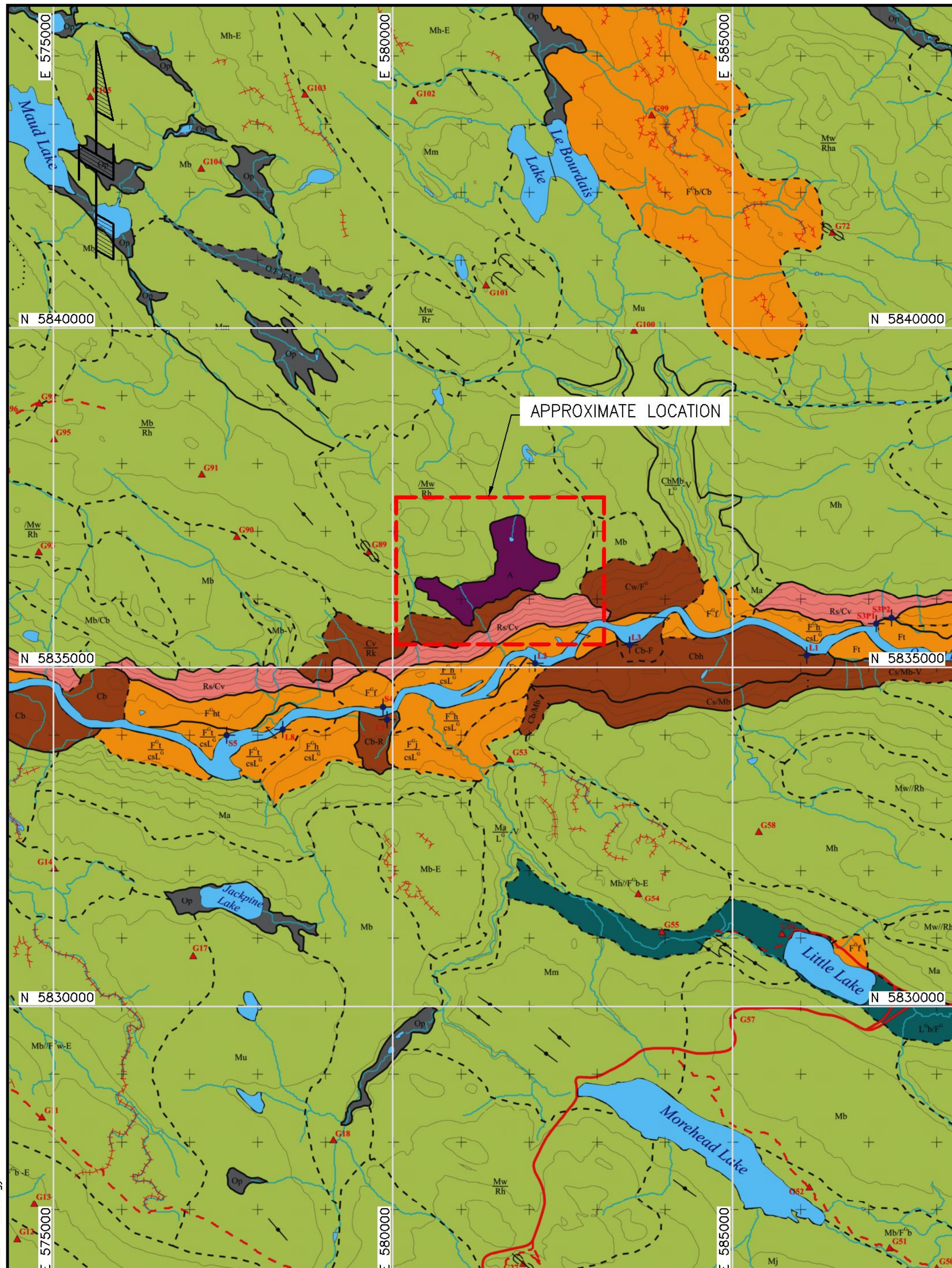
FIGURES



SYMBOLS

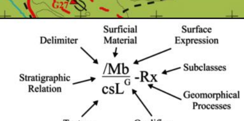
Terrain Boundaries
- Sharp
- Clear
- Gradational

Ice Flow/Contact Features
- Striae (bi-directional)
- Drumlin (uni-directional)
- Fluting (bi-directional)
- Craig and Tail (uni-directional)
- Melt Water Channel

Fieldwork Stations
- L1 Stratigraphic Section
- G1 Mapping Control Point

Geographical Features
- Contour (60 m interval)
- River/Stream

Roads
- Paved
- Gravel



Delimiter

/	Surficial material in front of symbol is more extensive than the following material **or** if no surficial material precedes symbol, then it indicates a partial covering of the following material
//	Surficial material in front of symbol is much more extensive than the following material
•	Surficial material in front of symbol is approximately equally extensive as the following material

Stratigraphic Relation

—	Indicates a stratigraphic relationship; read as a fraction, the material indicated in the numerator is found overlying the material described by the denomenator

Qualifier

G	Indicates the material has a glacial depositional origin
A	Indicates that the depositional environment in which the material was deposited is still active

Texture

c	Clay
g	Gravel
z	Silt
s	Sand

Surficial Material

A	Anthropogenic
C	Colluvium
F	Fluvial
L	Lacustrine
M	Morainal
O	Organic
R	Bedrock

Surface Expression

a	Moderate slope
b	Blanket
f	Fan
h	Hummocky
j	Gentle slope
k	Moderately steep slope
m	Rolling
p	Plain
r	Ridges
s	Steep slope
t	Terrace
u	Undulating
v	Veneer
w	Mantle of variable thickness

Geomorphical Processes

E	Channeled by meltwater
F	Slow mass movement
M	Meandering channel
R	Rapid mass movement
V	Gully erosion

Subclasses

e	Earthflow
x	Slump-flow

(Modified from Howes and Kenk 1997)

British Columbia Ministry of Energy and Mines

OPEN FILE 2003-7

QUATERNARY GEOLOGY OF THE HYDRAULIC MAP SHEET (NTS 93 A/12) BRITISH COLUMBIA

A.J. Bichler, University of Victoria
P.T. Bobrowsky, Geological Survey of Canada

Scale 1:50 000

SURFIAL GEOLOGY

QUATERNARY

Holocene

A — **ANTHROPOGENIC:** Surficial material that has been modified by human activities so that its natural physical properties (e.g. internal structure, compaction, cohesion) are no longer evident. Making up most of these materials are mine tailings as well as washed sand and gravel from placer mines.

O — **ORGANIC:** Thick accumulations of water-saturated, organic rich peat that occurs often as a level blanket of fibric material found in bogs, fens and other low-lying, poorly drained areas.

F — **FLUVIAL:** Cobble gravel with sand matrix associated with the avulsion of water courses. Sediment is deposited in gravel bars and low fluvial terraces. In subordinate valleys, fluvial sediments, consisting of fine to coarse sand found within the floodplains.

C — **COLLUVIUM:** Poorly sorted, sandy to gravelly diamicton with weak to weakly moderate compaction. Where colluvial deposits are the result of mass wasting of glaciolacustrine sediment, they tend to be clay or silt rich and contain organic debris. At the base of steep rock cliffs, colluvium is typically talus, composed of angular, cobble or boulder clasts.

Pleistocene

F^G — **GLACIOFLUVIAL:** Typically moderately sorted, weak to moderately compacted, cobble or boulder cobble gravel with a sand matrix. Clasts are rounded to subrounded. They are found as well-defined terraces in the major valleys up to approximately 70 m above river level or as irregular deposits at higher elevations on valley slopes or on plateaus. They are associated with melt-water channels or drainage courses.

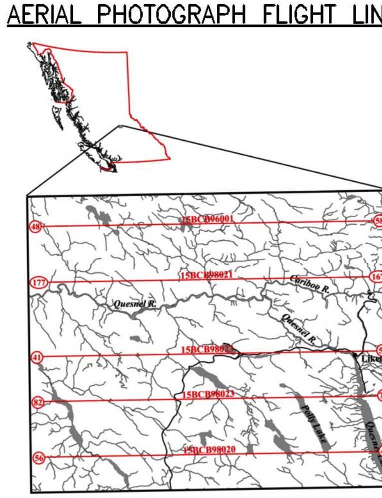
L^G — **GLACIOLACUSTRINE:** Thick accumulations of interbedded sand, silt, and clay. May also occur as rhythmically bedded silt and clay. In large exposures, a general coarsening upwards succession is observed, often capped by a massive unit of clay or silt. This succession most notably occurs in the major valleys, underlying fluvial and glaciofluvial terraces.

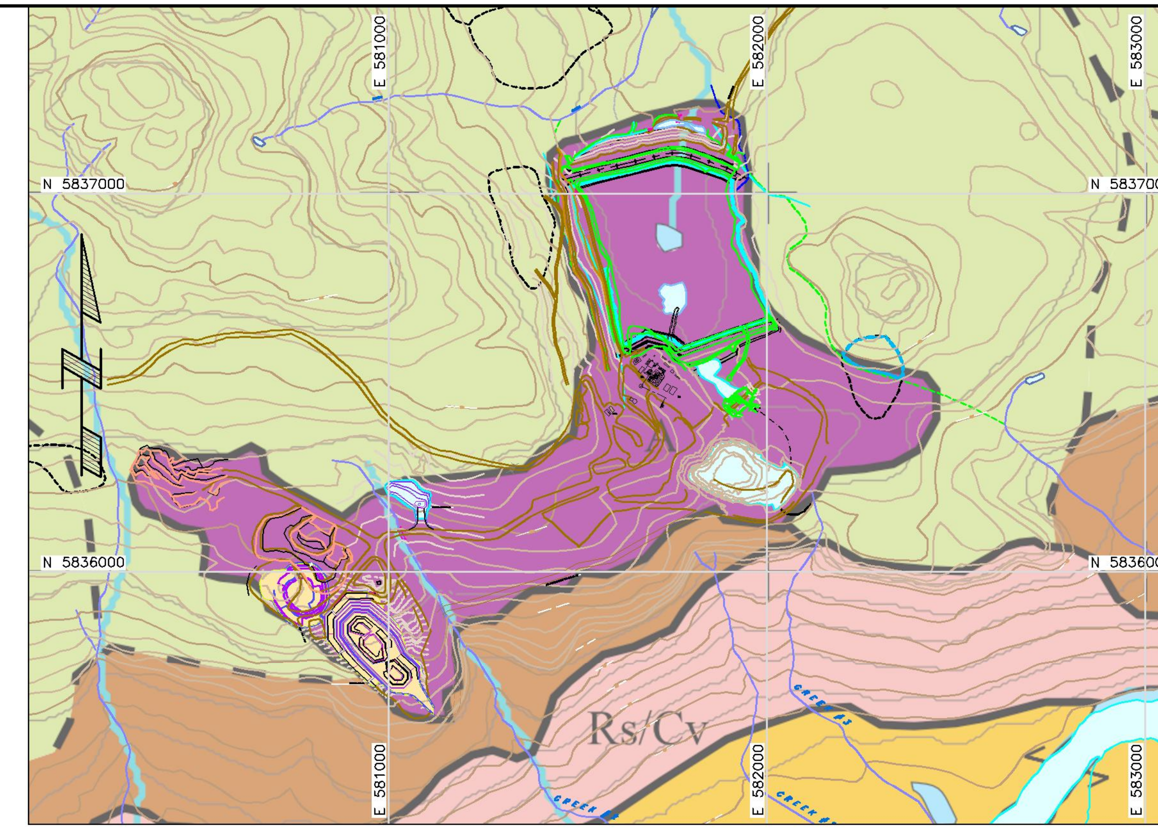
M — **MORAINAL:** Poorly sorted, moderate to well compacted, clayey to silty diamicton. Clasts are subrounded to subangular, range from pebbles to boulders and may be faceted and/or striated. Interpreted as lodgement till. Irregular sand and gravel lenses may be present where till was deposited subaqueously or in association with flowing water. At higher elevations, in the northeast region of the map sheet, less compact, boulder rich ablation till exists.

Pre-Quaternary

R — **BEDROCK:** Quesnel Terrane, upper Triassic to lower Jurassic rocks related to a volcanic arc.

AERIAL PHOTOGRAPH FLIGHT LINES





LOCATION AREA

NOT TO SCALE

REFERENCES

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RECOMMENDED CITATION

Bichler, A.J. and Bobrowsky, P.T., 2003. Quaternary geology of the Hydraulic map sheet (NTS 93/A12), British Columbia. British Columbia Geosciences, Research and Development Branch, Open File 2003-7, scale 1:50 000.

NOTES:

1. REGIONAL GEOLOGY MAP PROJECTION: UNIVERSAL TRANSVERSE MERCATOR GRID ZONE 10 DATUM: NAD 83.
2. REGIONAL SURFICIAL GEOLOGY OBTAINED FROM GEOLOGICAL SURVEY OF CANADA (GSC).
3. SITE PLAN FROM KCB (2014).
4. THE SCALE OF SURFICIAL MAPPING IS NOT ACCURATE WITHIN THE AREA OF THE QR TSF. HOWEVER, THE REGIONAL GEOLOGY SUGGESTS SOILS AT THE SITE CONSIST OF ANTHROPOGENIC FILL, UNDERLAIN BY MORAINAL AND COLLUVIAL DEPOSITS.

NOT FOR CONSTRUCTION

TO BE READ WITH KLOHN CRIPPEN BERGER REPORT DATED JUNE, 2015

CLIENT	PROJECT
BARKERVILLE GOLD MINES	QR MINE – RESPONSE TO MEM
Klohn Crippen Berger	TITLE: SURFICIAL GEOLOGY
	PROJECT No. M09672 A07 — FIG. No. 1

KCR-BM

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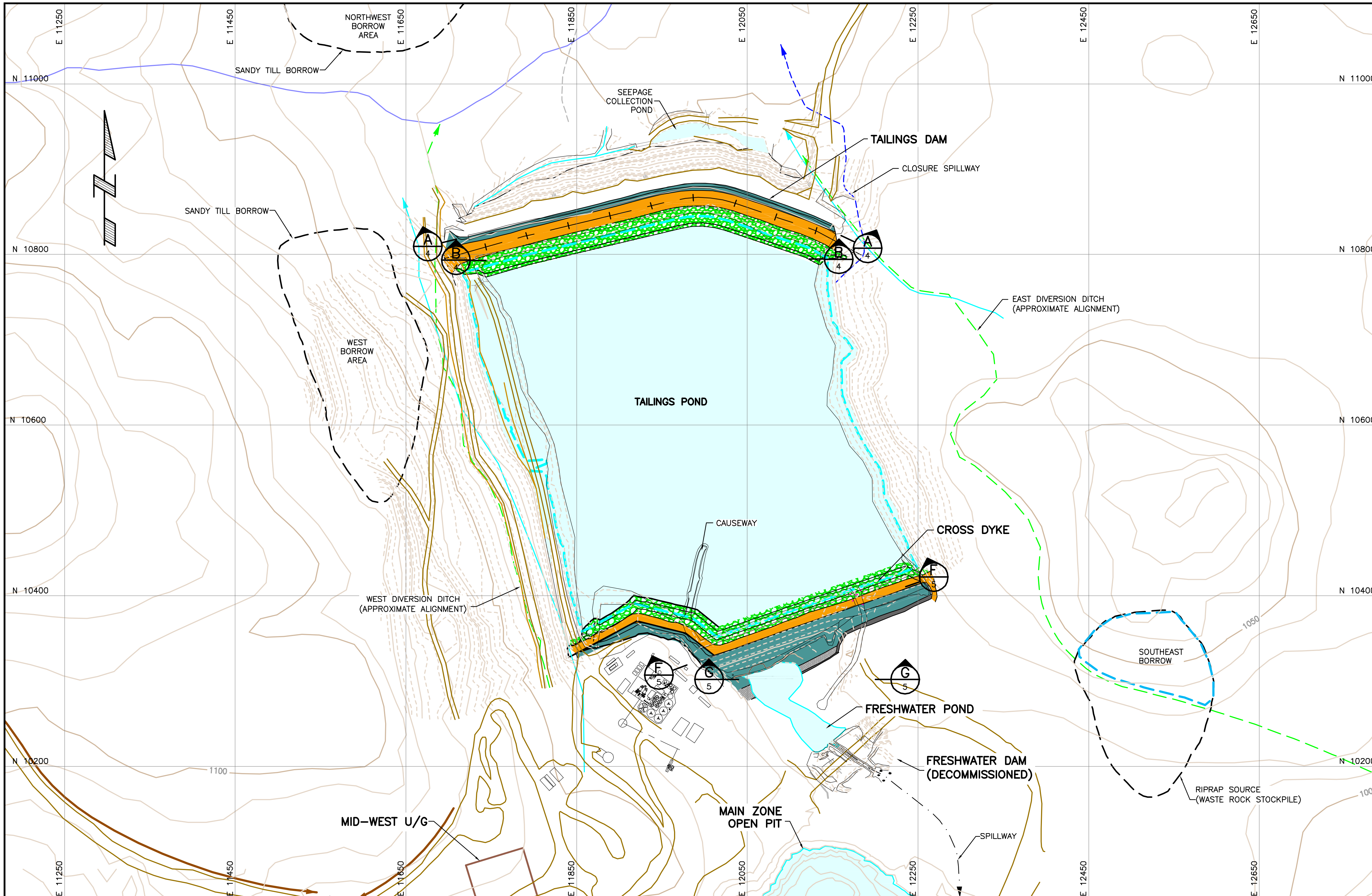
Image File(s): BGM Logo FIG1-OF2003-07-1_02 SatelliteImage-FromGoogleEarth – Geology



LEGEND

- CREEK
- DIVERSION DITCH
- ROAD DITCH
- ROAD
- CULVERT
- GEOLOGIC SECTIONS

GENERAL NOTES:

1. REGIONAL CONTOURS DIGITIZED FROM QR CLAIMS MAP, DOME EXPLORATION (CANADA) LTD. DEC. 1987, BASED ON NTS No. 93A/12
2. MAIN ZONE PIT AREA BASED ON SURVEY BY KINROSS AUGUST, 1997. FRESHWATER POND AND TAILINGS POND BOUNDARIES ARE ESTIMATED.
3. DIVERSION DITCH ALIGNMENTS SHOWN ON THE DRAWINGS ARE DESIGN ALIGNMENTS, OR ESTIMATED BY OBSERVATIONS MADE DURING ANNUAL SITE VISITS.
4. CONSTRUCTION RECORD DRAWINGS BASED ON SURVEY DATA PROVIDED BY ROKTEK, (SEPTEMBER, 2014) AND FIELD OBSERVATIONS. REFER TO 2014 CONSTRUCTION SUMMARY REPORT (KCB).
5. REFER TO FIGURES 5 AND 6 FOR LEGEND OF EMBANKMENT FILL MATERIALS.

NOT FOR CONSTRUCTION

TO BE READ WITH KLOHN CRIPPEN BERGER REPORT DATED JUNE, 2015

SCALE 0 100 m

CLIENT: BARKERVILLE GOLD MINES

Klohn Crippen Berger

PROJECT: QR MINE – RESPONSE TO MEM

TITLE: TAILINGS STORAGE FACILITY GENERAL ARRANGEMENT

PROJECT No. M09672 A07

FIG. No. 2

KCR-BM

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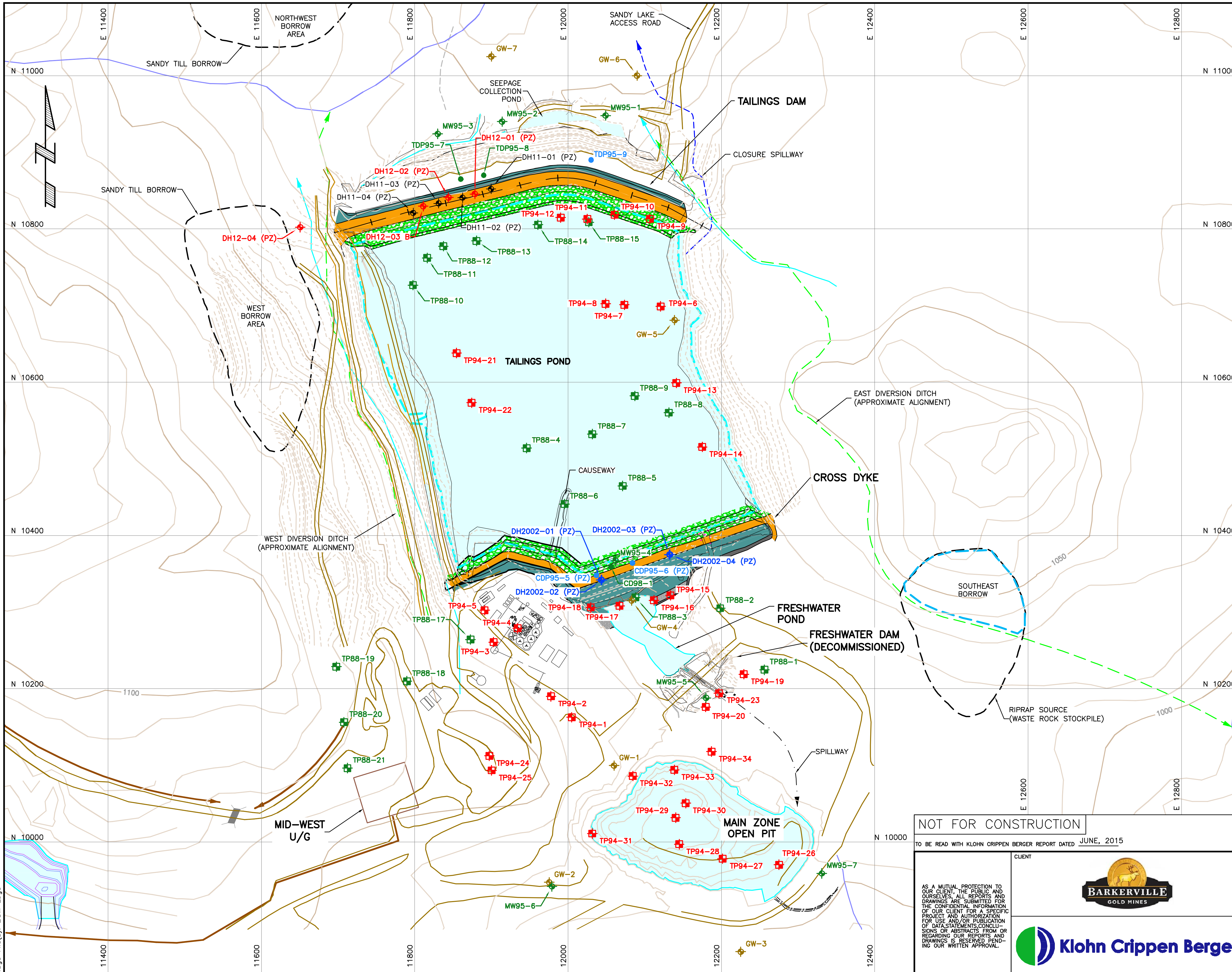
Image File(s): BGM Logo



LEGEND

- CREEK
- DIVERSION DITCH
- ROAD DITCH
- ROAD
- CULVERT
- DRILL HOLES, SRK 1990.
- DRILL HOLES, KC 1995
- DRILL HOLES, KC 2002
- DRILL HOLES, KCB 2011.
- DRILL HOLES, KCB 2012.
- TEST PIT, KC 1994
- TEST PIT, KC 1995
- TEST PIT, SRK 1994
- TEST PIT, SRK 1988
- PIEZOMETER NON-OPERATIONAL

GENERAL NOTES:

1. REGIONAL CONTOURS DIGITIZED FROM QR CLAIMS MAP, DOME EXPLORATION (CANADA) LTD. DEC. 1987, BASED ON NTS No. 93A/12
2. MAIN ZONE PIT AREA BASED ON SURVEY BY KINROSS AUGUST, 1997. FRESHWATER POND AND TAILINGS POND BOUNDARIES ARE ESTIMATED.
3. DIVERSION DITCH ALIGNMENTS SHOWN ON THE DRAWINGS ARE DESIGN ALIGNMENTS, OR EXPECTED BY OBSERVATIONS MADE DURING ANNUAL SITE VISITS.
4. CONSTRUCTION RECORD DRAWINGS BASED ON SURVEY DATA PROVIDED BY ROKTEK, (SEPTEMBER, 2014) AND FIELD OBSERVATIONS.
5. REFER TO FIGURES 5 AND 6 FOR LEGEND OF EMBANKMENT FILL MATERIALS.

SCALE 0 100 m

NOT FOR CONSTRUCTION

TO BE READ WITH KLOHN CRIPPEN BERGER REPORT DATED JUNE, 2015

CLIENT: BARKERVILLE GOLD MINES

Klohn Crippen Berger

PROJECT: QR MINE – RESPONSE TO MEM

TITLE: TEST PITS, DRILL HOLES AND PIEZOMETER PLAN

PROJECT No. M09672 A07

FIG. No. 3

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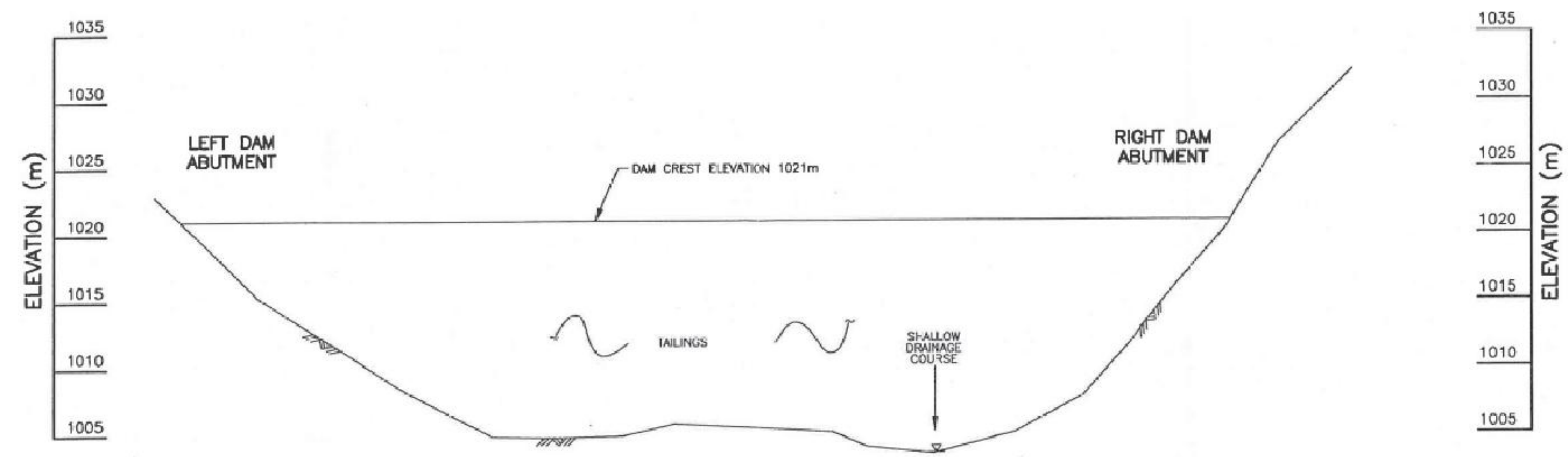
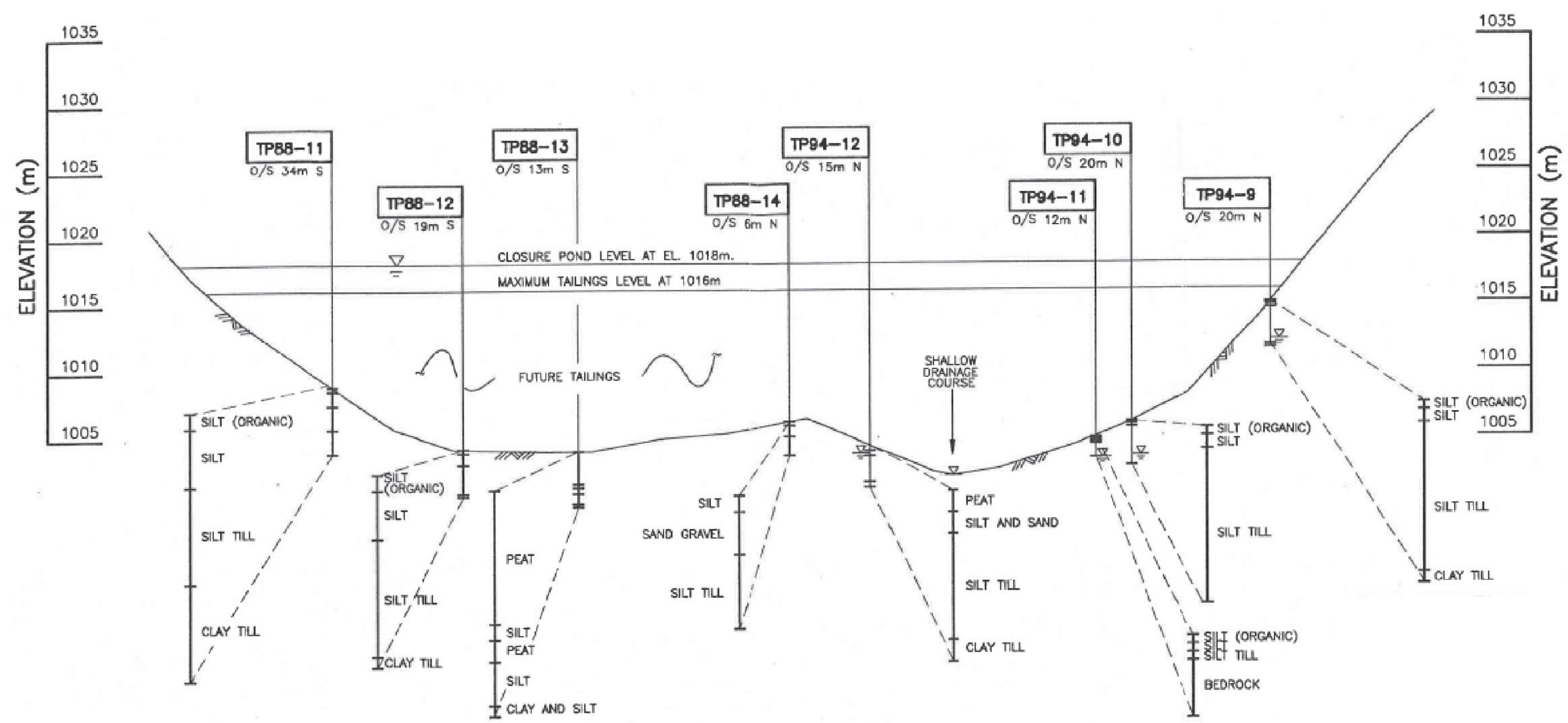


SECTION A
NOT TO SCALE 2



SECTION B
NOT TO SCALE 2

NOTES:

1. SEE FIGURE 2 FOR GENERAL NOTES.
2. SECTIONS REPRODUCED FROM KC REPORT, "QR GOLD PROJECT, TAILINGS IMPOUNDMENT AND FRESHWATER POND, FINAL DESIGN OF OPERATING FACILITIES", DATE AUGUST 15, 1994.
3. THE VERTICAL SCALE IS EXAGGERATED 5X

NOT FOR CONSTRUCTION

TO BE READ WITH KLOHN CRIPPEN BERGER REPORT DATED JUNE, 2015

CLIENT
BARKERVILLE GOLD MINES

Klohn Crippen Berger

PROJECT
QR MINE – RESPONSE TO MEM

TITLE
SURFICIAL GEOLOGICAL SECTIONS NORTH DAM

PROJECT No. M09672 A07

FIG. No. 4

KCR-BM

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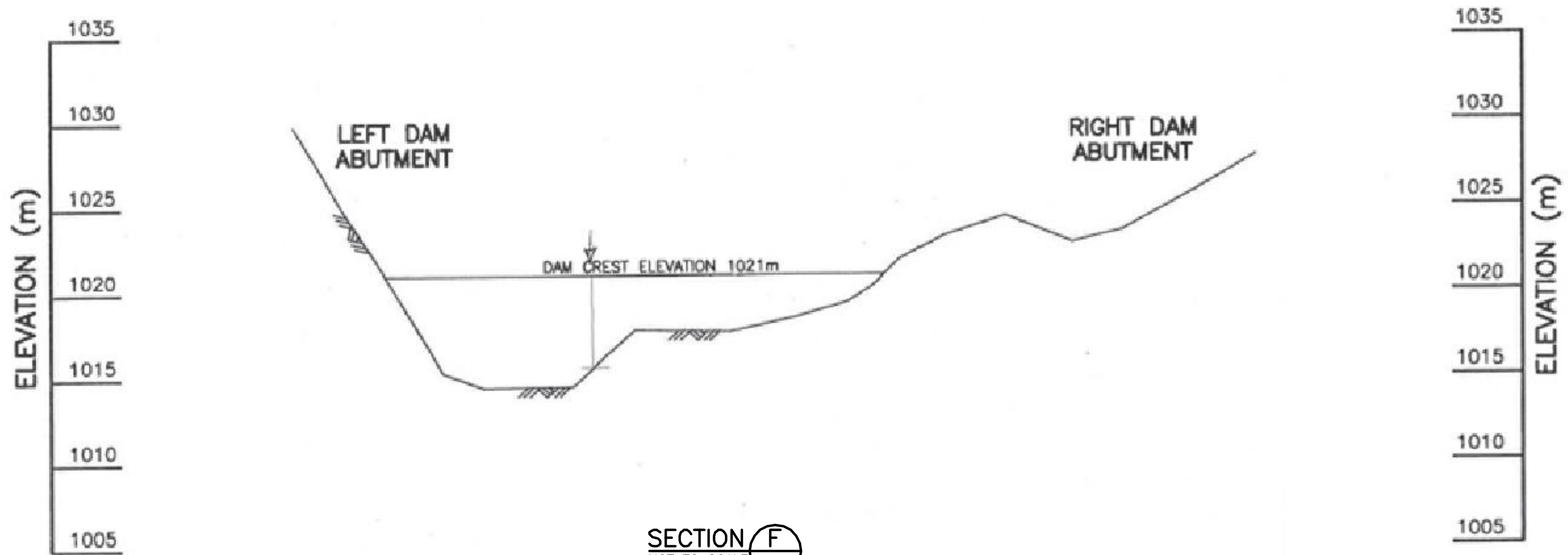
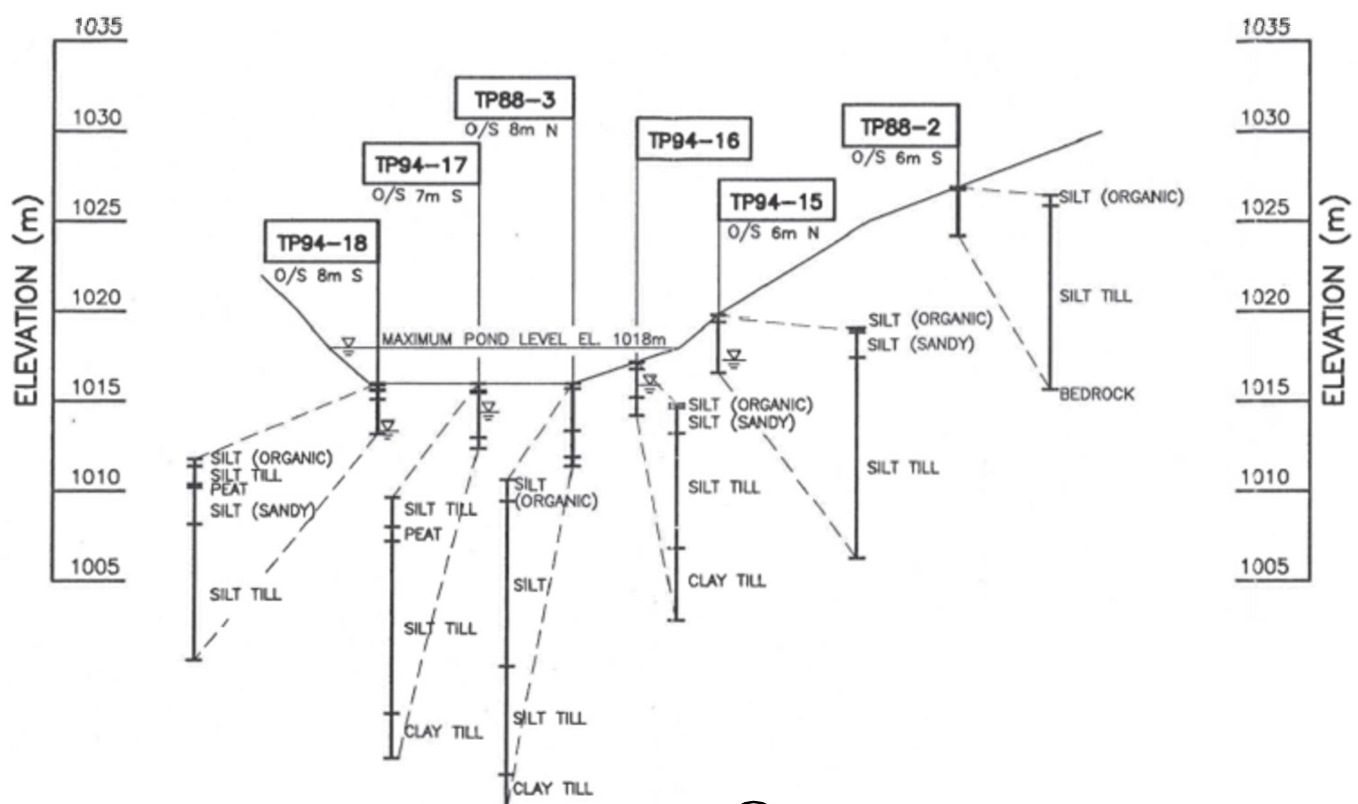


SECTION F/2
NOT TO SCALE



SECTION G/2
NOT TO SCALE

NOTES:

1. SEE FIGURE 2 FOR GENERAL NOTES.
2. SECTIONS REPRODUCED FROM KC REPORT, "QR GOLD PROJECT, TAILINGS IMPOUNDMENT AND FRESHWATER POND, FINAL DESIGN OF OPERATING FACILITIES", DATE AUGUST 15, 1994.
3. THE VERTICAL SCALE IS EXAGGERATED 5X

NOT FOR CONSTRUCTION

TO BE READ WITH KLOHN CRIPPEN BERGER REPORT DATED JUNE, 2015

CLIENT: BARKERVILLE GOLD MINES

Klohn Crippen Berger

PROJECT: QR MINE – RESPONSE TO MEM

TITLE: SURFICIAL GEOLOGICAL SECTIONS CROSS DYKE

PROJECT No. M09672 A07

FIG. No. 5

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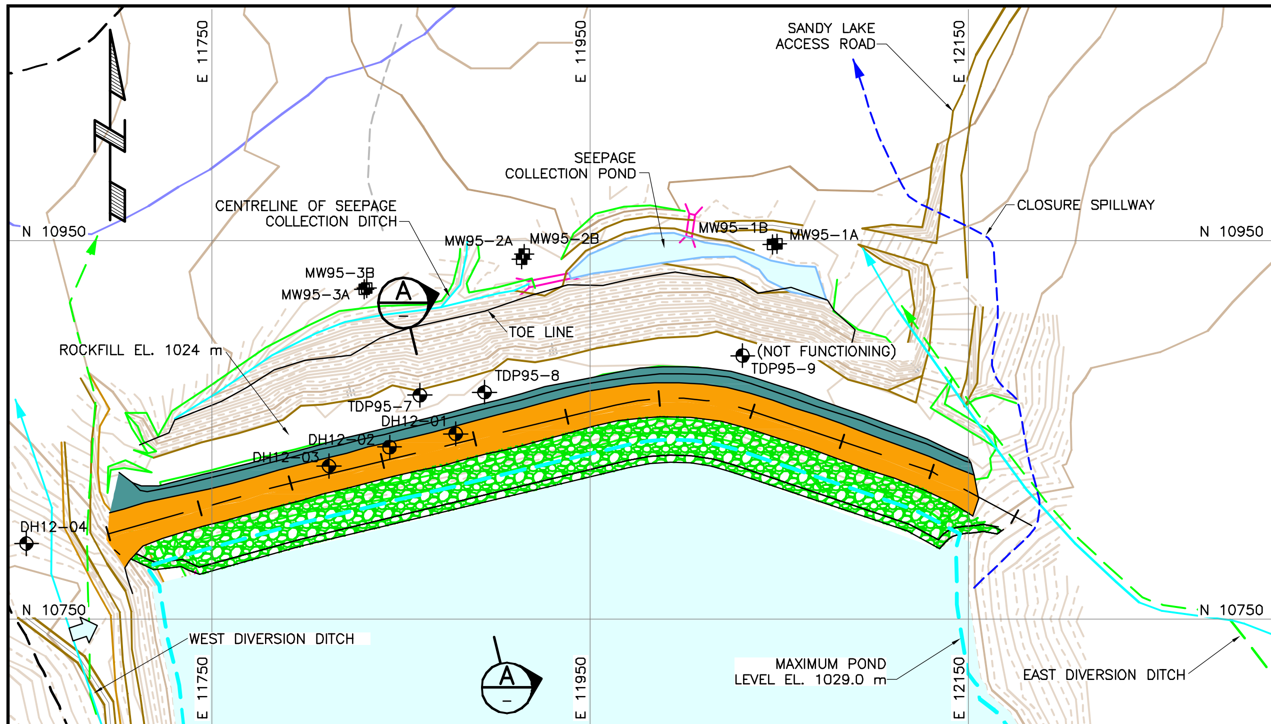
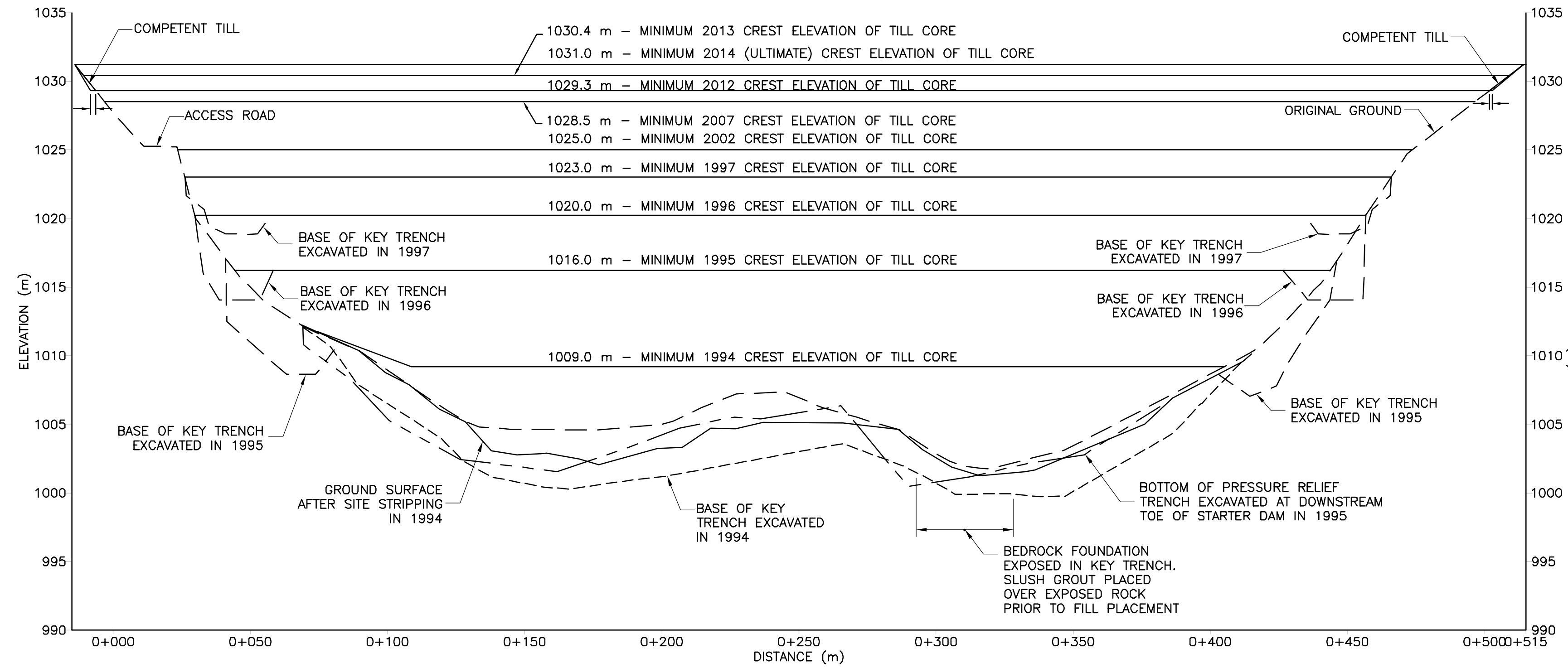
Xref File(s):
Image File(s): BGM Logo FIG5-Cross dyke sections

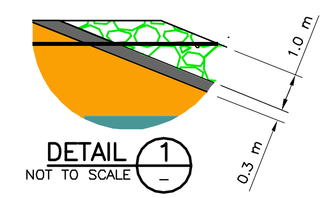
KCR-BM



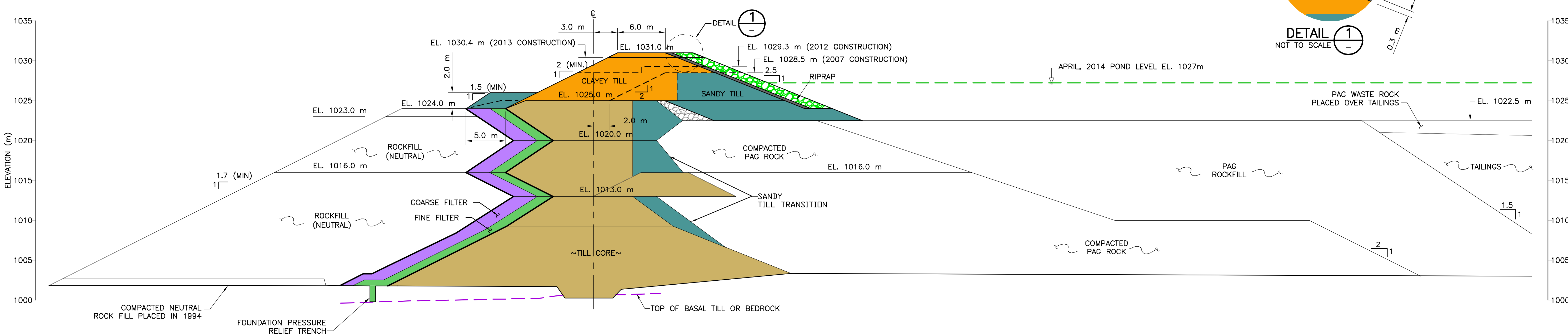
TAILINGS DAM PLAN
SCALE A



PROFILE
VERT. SCALE B
HORIZ. SCALE C



DETAIL 1
NOT TO SCALE



SECTION A
SCALE C

SCALE A 0 100 m
SCALE B 0 50 m
SCALE C 0 10 m

LEGEND

- TILL CORE
- CLAYEY TILL
- SANDY TILL
- RIPRAP FILTER MATERIAL
- RIPRAP
- COARSE FILTER
- FINE FILTER
- NEUTRAL WASTE ROCK OR RIPRAP
- DH12-01 2012 DRILLHOLE WITH PIEZOMETER
- TDP95-7 PIEZOMETER
- MW95-3A MONITORING WELL

GENERAL NOTES:

1. REGIONAL CONTOURS DIGITIZED FROM QR CLAIMS MAP, DOME EXPLORATION (CANADA) LTD. DEC. 1987, BASED ON NTS No. 93A/12
2. MAIN ZONE PIT AREA BASED ON SURVEY BY KINROSS AUGUST, 1997. FRESHWATER POND AND TAILINGS POND BOUNDARIES ARE ESTIMATED.
3. DIVERSION DITCH ALIGNMENTS SHOWN ON THE DRAWINGS ARE DESIGN ALIGNMENTS, OR ESTIMATED BY OBSERVATIONS MADE DURING ANNUAL SITE VISITS.
4. CONSTRUCTION RECORD DRAWINGS BASED ON SURVEY DATA PROVIDED BY ROKTEK, (SEPTEMBER, 2014) AND FIELD OBSERVATIONS. REFER TO 2014 CONSTRUCTION SUMMARY REPORT (KCB)

NOT FOR CONSTRUCTION

TO BE READ WITH KLOHN CRIPPEN BERGER REPORT DATED JUNE, 2015

CLIENT: BARKERVILLE GOLD MINES

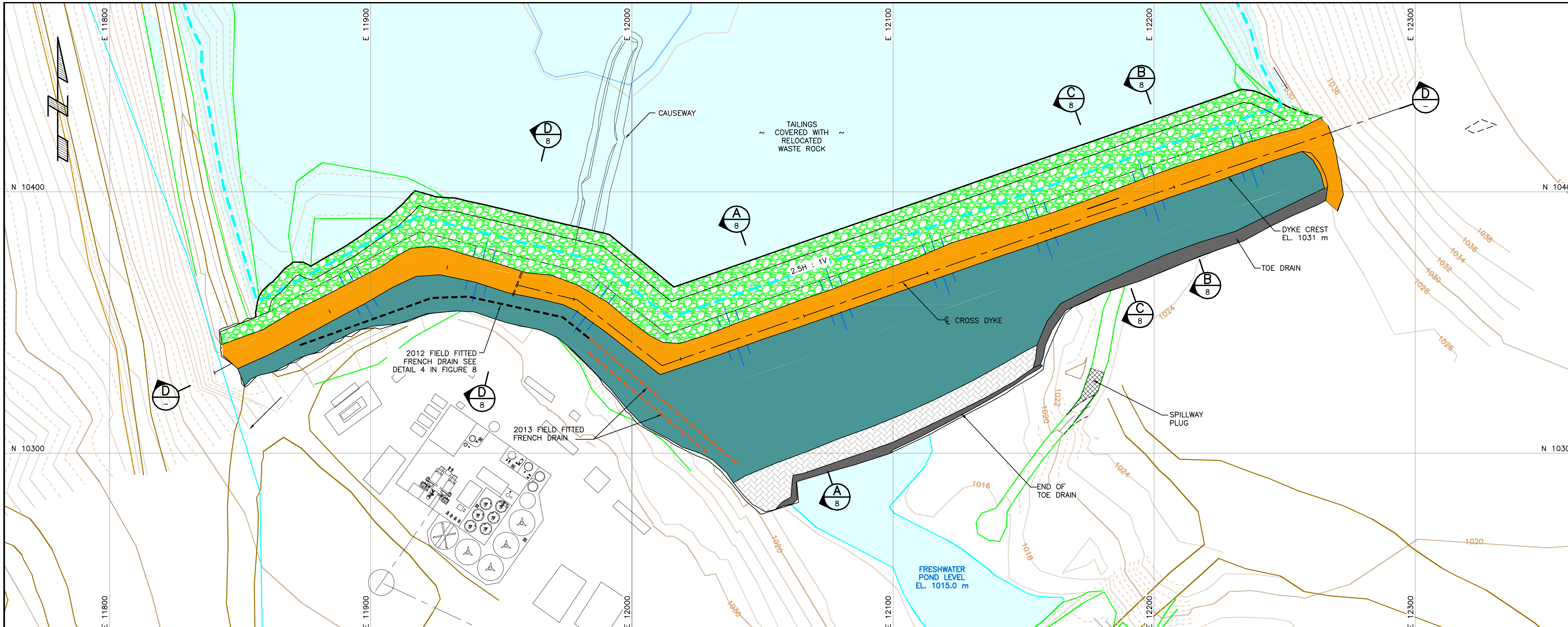
Klohn Crippen Berger

PROJECT: QR MINE – RESPONSE TO MEM

TITLE: NORTH DAM PLAN AND SECTIONS

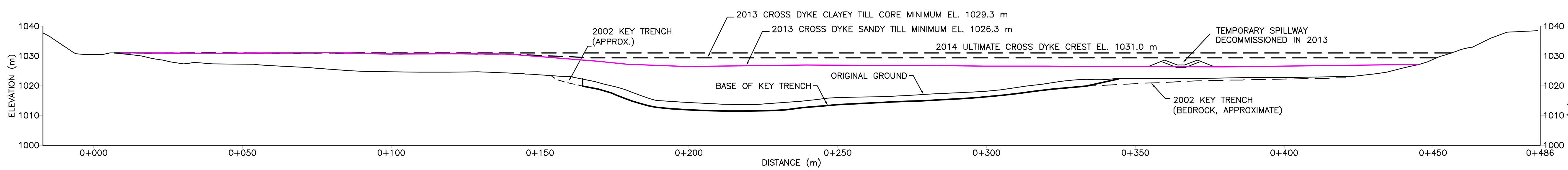
PROJECT No. M09672 A07

FIG. No. 6



CROSS DYKE PLAN

SCALE A



SECTION D –

SCALE A

NOT FOR CONSTRUCTION

TO BE READ WITH KLOHN CRIPPEN BERGER REPORT DATED JUNE, 2015

SCALE A 0 40 m

LEGEND

- CLAYEY TILL
- SANDY TILL
- RIPRAP FILTER MATERIAL
- RIPRAP
- FINE FILTER (TOE DRAIN)

NOTE:

1. SEE FIGURE 2 FOR GENERAL NOTES.

CLIENT: BARKERVILLE GOLD MINES

Klohn Crippen Berger

PROJECT: QR MINE – RESPONSE TO MEM

TITLE: CROSS DYKE PLAN AND PROFILE

PROJECT No. M09672 A07

FIG. No. 7

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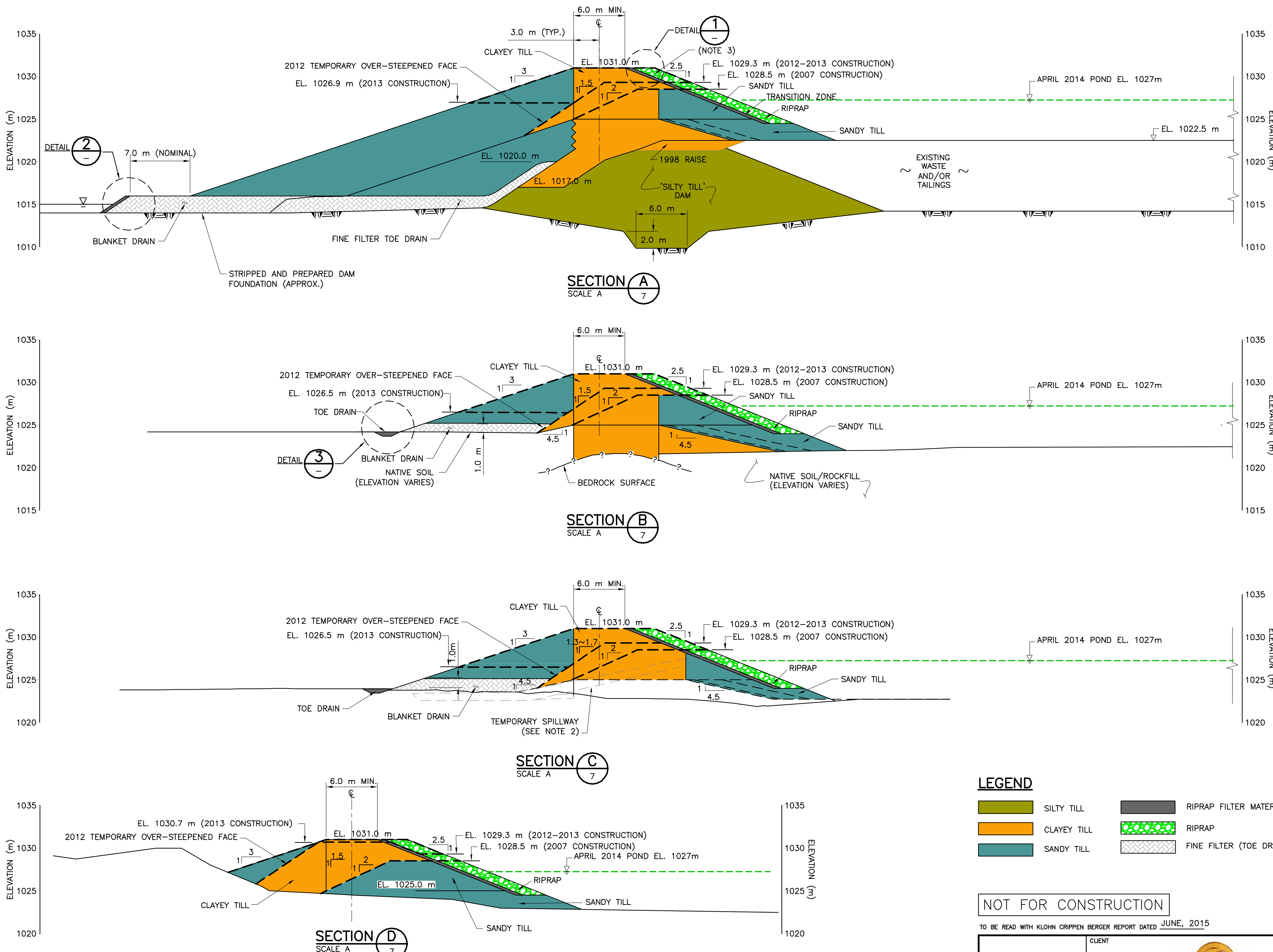

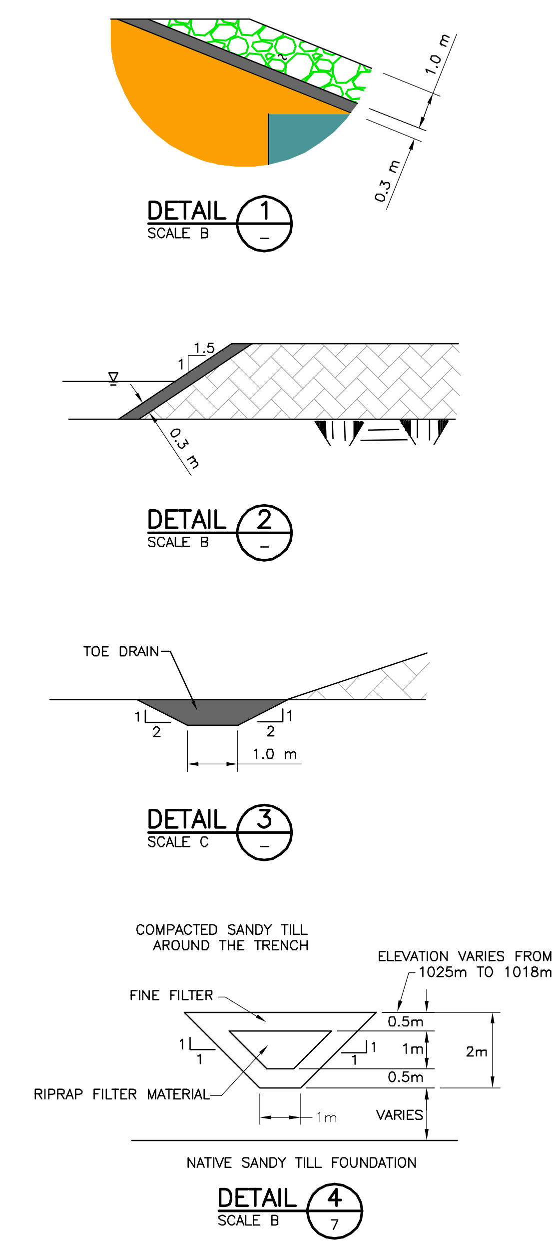

FRENCH DRAIN – TYPICAL SECTION

LEGEND

SILTY TILL	RIPRAP FILTER MATERIAL
CLAYEY TILL	RIPRAP
SANDY TILL	FINE FILTER (TOE DRAIN)

SCALE A: 0 – 10 m
SCALE B: 0 – 4 m
SCALE C: 0 – 5 m

NOT FOR CONSTRUCTION

TO BE READ WITH KLOHN CRIPPEN BERGER REPORT DATED JUNE, 2015

NOTES:

1. SEE FIGURE 2 FOR GENERAL NOTES.
2. THE TEMPORARY SPILLWAY WAS DECOMMISSIONED IN 2013.

CLIENT: BARKERVILLE GOLD MINES

Klohn Crippen Berger

PROJECT: QR MINE – RESPONSE TO MEM

TITLE: 2014 CROSS DYKE SECTIONS

PROJECT No. M09672 A07

FIG. No. 8

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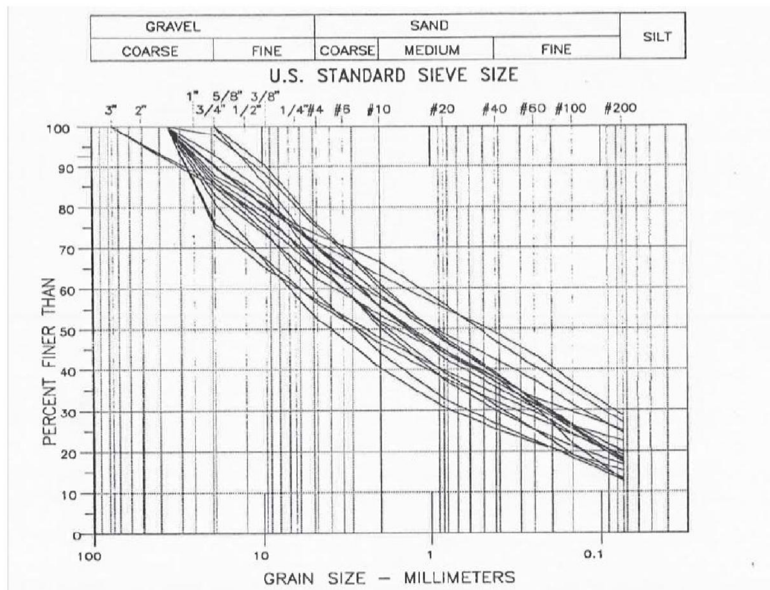
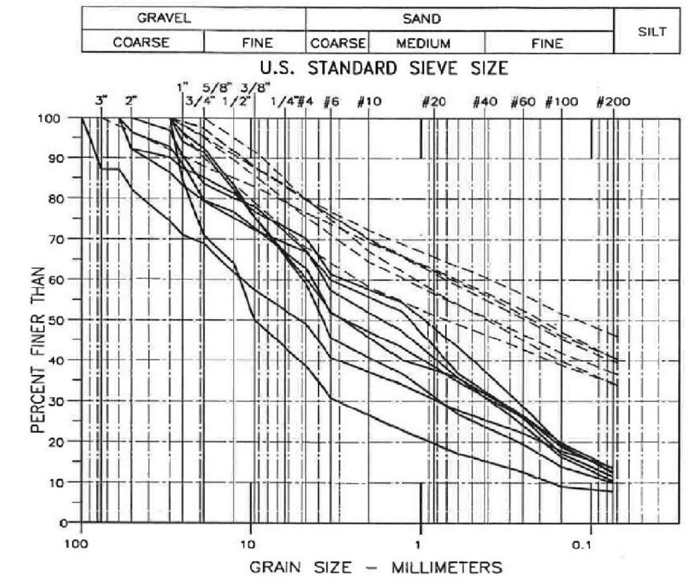


GLACIAL TILL (AS BUILT, 1994)

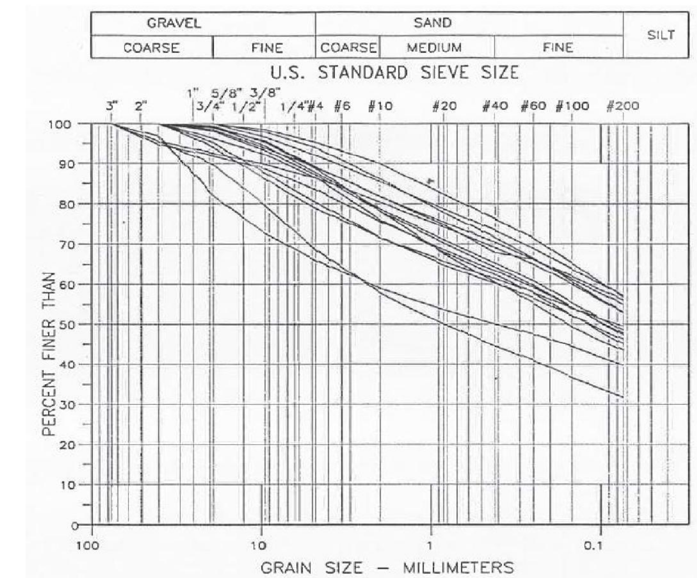
NOTES:
PARTICLE SIZE DISTRBUTIONS FROM TAILINGS IMPOUNDMENT FRESH WATER POND - STAGE 1 AS BUILT, REPORT DATED FEBRUARY 28, 1995 (KL)



GLACIAL TILL (AS BUILT, 1995)

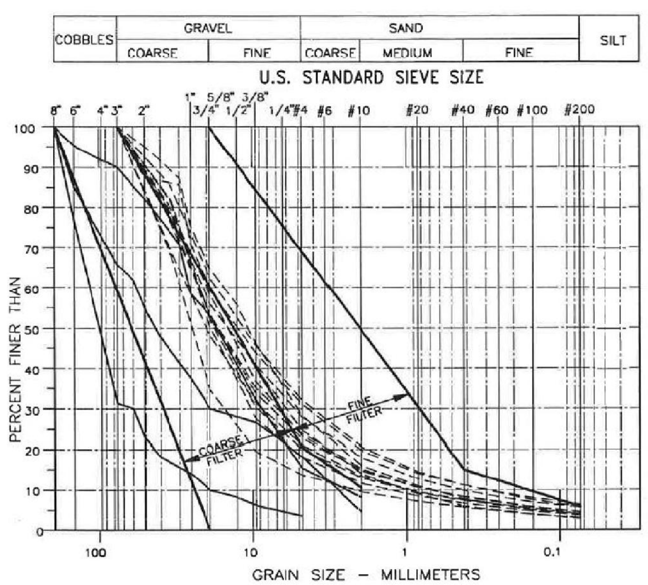
LEGEND:
——— MAIN ZONE BORROW USED FOR PHASE 1 CONSTRUCTION (EL. 1009m TO EL 1013m)
– – – WEST ZONE BORROW USED FOR PHASE 2 CONSTRUCTION (EL. 1013m TO EL 1015m)

NOTES:
PARTICLE SIZE DISTRIBUTION CHART FROM 1995 - ANNUAL REVIEW AND AS BUILT, REPORT DATED APRIL 19, 1996 (KL)
SOLID LINE REPRESENTS PHASE 1 TILL (BELOW ELEVATION 1013 M), DASHED LINE



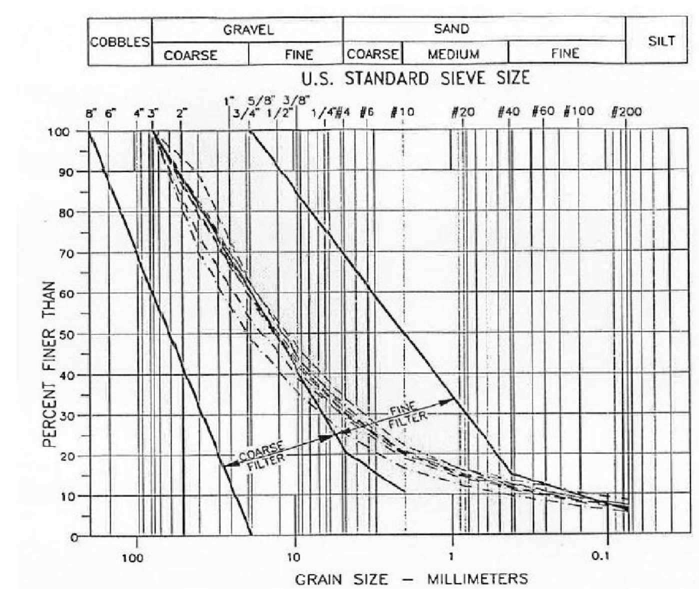
GLACIAL TILL (AS BUILT, 1996)

NOTES:
PARTICLE SIZE DISTRIBUTION CHART FROM 1996 - ANNUAL REVIEW AND AS BUILT, REPORT DATED JUNE 3, 1997 (KC)



FINE FILTER AND COARSE FILTERS (AS BUILT, 1995)

NOTES:
PARTICLE SIZE DISTRBUTIONS FROM TAILINGS IMPOUNDMENT FRESH WATER POND - STAGE 1 AS BUILT, REPORT DATED FEBRUARY 28, 1995 (KL)



FINE FILTERS (AS BUILT, 1996)

LEGEND:
– – – FINE FILTER GRADATION CURVES FOR EL. 1013m TO EL. 1016m.
–·–·– FINE FILTER GRADATION CURVES FOR EL. 1016m TO EL. 1020m.
——— FILTER GRADATION LIMITS

NOTES:
PARTICLE SIZE DISTRIBUTION CHART FROM 1996 - ANNUAL REVIEW AND AS BUILT, REPORT DATED JUNE 3, 1997 (KC)

NOT FOR CONSTRUCTION

TO BE READ WITH KLOHN CRIPPEN BERGER REPORT DATED JUNE, 2015

NOT TO SCALE

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CLIENT
BARKERVILLE GOLD MINES

Klohn Crippen Berger

PROJECT
QR MINE – RESPONSE TO MEM

TITLE
DESIGN AND AS–BUILT
PARTICLE SIZE GRADATION ENVELOPES
NORTH DAM

PROJECT No.
M09672 A07

FIG. No.
9

KCR-BM

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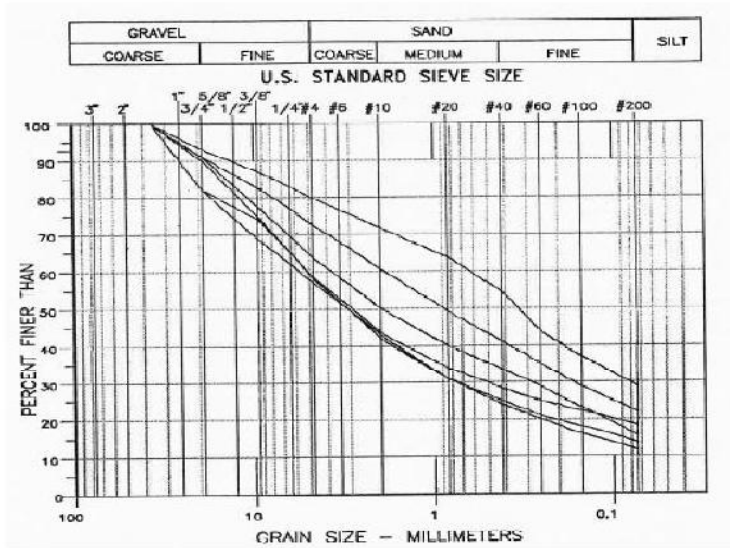
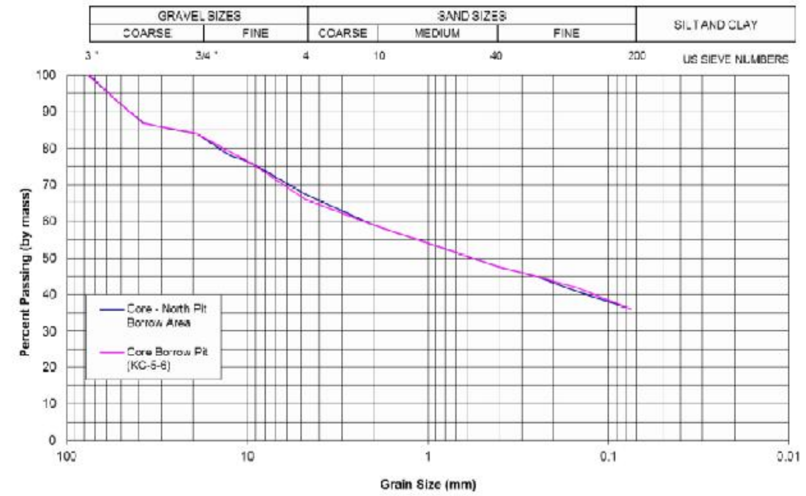


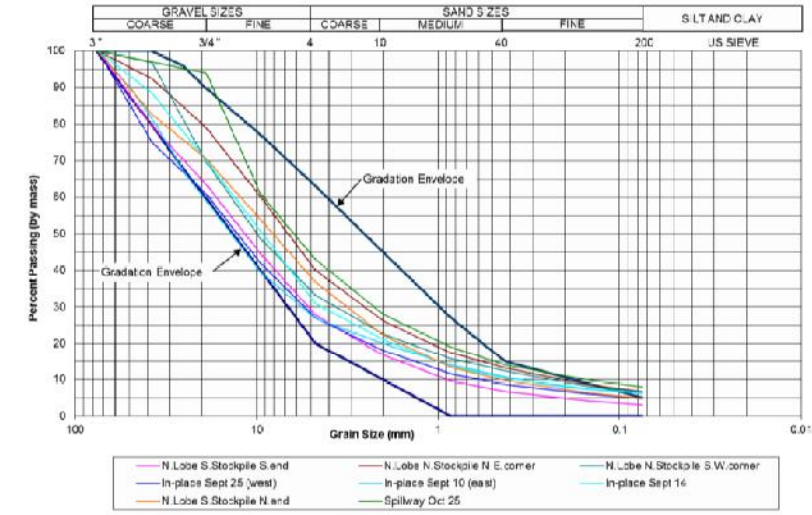
SILTY TILL CORE (AS-BUILT, 1994)

NOTES
PARTICLE SIZE DISTRIBUTIONS FROM TAILINGS IMPOUNDMENT FRESH WATER POND - STAGE 1 AS BUILT, REPORT DATED FEBRUARY 28, 1995 (KL)



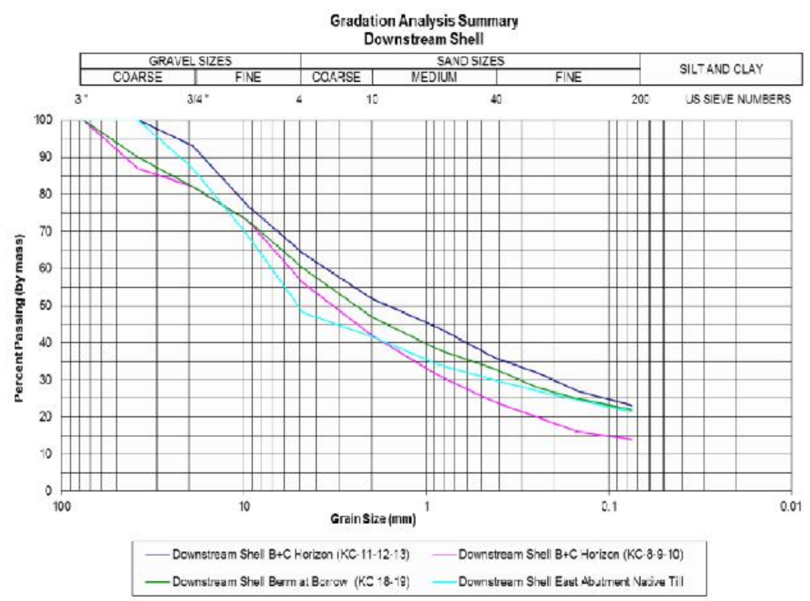
CLAYEY TILL CORE (AS BUILT, 2002)

NOTES
PARTICLE SIZE DISTRIBUTIONS FROM QR MINE 2002 PERMANENT CLOSURE CONSTRUCTION SUMMARY DATED MARCH 31, 2003 (KL)



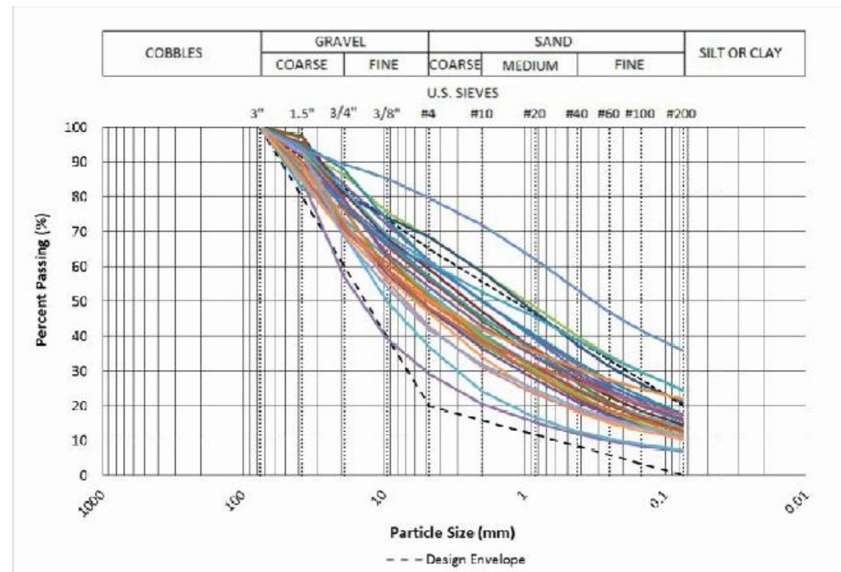
FINE FILTER TOE DRAIN (AS BUILT, 2002)

NOTES
PARTICLE SIZE DISTRIBUTIONS FROM QR MINE 2002 PERMANENT CLOSURE CONSTRUCTION SUMMARY DATED MARCH 31, 2003 (KL)



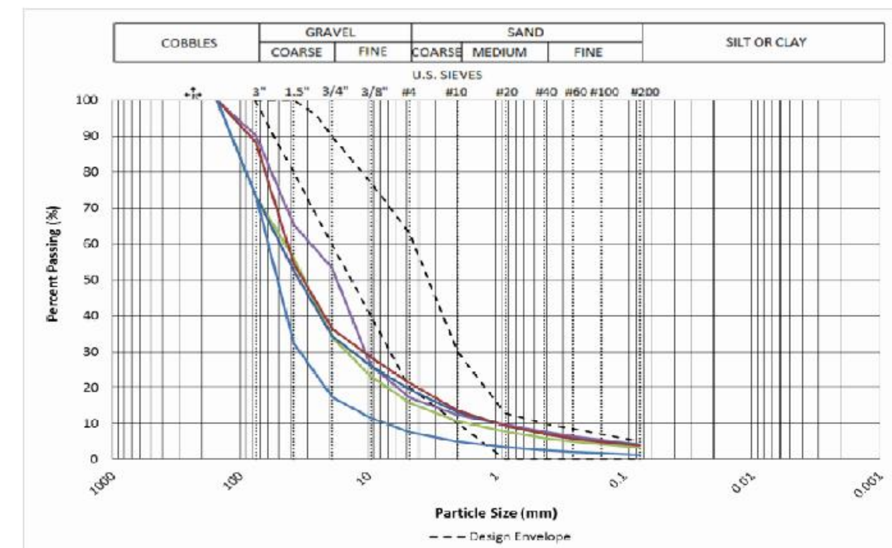
SANDY TILL DOWNSTREAM SHELL (AS BUILT, 2002)

NOTES
PARTICLE SIZE DISTRIBUTIONS FROM QR MINE 2002 PERMANENT CLOSURE CONSTRUCTION SUMMARY DATED MARCH 31, 2003 (KL)



SANDY TILL DOWNSTREAM SHELL (AS BUILT, 2012-2013)

NOTES
PARTICLE SIZE DISTRIBUTIONS FROM INTERIM STATUS CONSTRUCTION SUMMARY-REV.1 DATED MAY 15, 2014 (KL)



BLANKET DRAIN (FINE FILTER TOE DRAIN) (AS BUILT, 2012-2013)

NOTES
PARTICLE SIZE DISTRIBUTIONS FROM INTERIM STATUS CONSTRUCTION SUMMARY-REV.1 DATED MAY 15, 2014 (KL)

NOT FOR CONSTRUCTION

TO BE READ WITH KLOHN CRIPPEN BERGER REPORT DATED JUNE, 2015

NOT TO SCALE

CLIENT
BARKERVILLE GOLD MINES
Klohn Crippen Berger

PROJECT
QR MINE – RESPONSE TO MEM

TITLE
DESIGN AND AS-BUILT
PARTICLE SIZE GRADATION ENVELOPES
CROSS DYKE

PROJECT No. M09672 A07
FIG. No. 10

KCR-BM

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Xref File(s):
Image File(s): BGM Logo PSD calc-crossdyke-rev1_01

APPENDIX I

MEM February 3, 2015 Memorandum

February 3, 2015

To: Kevin McMurren, Mine Manager - QR Mine - Barkerville Gold Mines Ltd

As you know, the Expert Panel that was convened to examine the Mount Polley tailings dam breach has issued a report on their findings. This report has been made public and you may already be familiar with the conclusions of this report. Chief among these was the determination that the failure at Mount Polley was related to the presence of weak glacio-lacustrine soils in the dam foundation. The Panel also indicated that the severity of the consequence of failure was in large part owing to the quantity of stored water and the proximity of this water to the dam embankment (i.e. lack of beach). The Ministry of Energy and Mines (MEM) requires confirmation that the conditions that lead to the incident at Mount Polley are not present at other mines in B.C.

More specifically, you are required to undertake an assessment to determine if the dam(s) associated with your tailings storage facility/facilities may be at risk due to:

1. Undrained shear failure of silt and clay foundations;
    a. Including a determination with respect to whether or not similar foundation conditions exist below the dams on your site,
    b. Whether or not sufficient site investigation (drill holes, etc.) has been completed to have confidence in this determination,
    c. If present, whether or not the dam design properly accounts for these materials, and
    d. If any gaps have been identified, a plan and schedule for additional sub-surface investigation.

2. Water balance adequacy;
    a. Including the total volume of surplus mine site water (if any) stored in the tailings storage facility,
    b. The volume of surplus mine water that has been added to the facility over each of the past five years,
    c. Any plans that are in place or that are under development to release surplus mine water to the environment,
    d. Recommended beach width(s), and the ability of the mine to maintain these widths,
    e. The ability of the TSF embankments to undergo deformation without the release of water (i.e. the adequacy of the recommended beach width),
    f. Provisions and contingencies that are in place to account for wet years, and
    g. If any gaps have been identified, a plan and schedule for addressing these issues.

3. Filter adequacy;
    a. Including the beach width and filter specifications necessary to prevent potential piping,
    b. Whether or not the filter has been constructed in accordance with the design, and
    c. If any gaps have been identified, a plan and schedule for addressing these issues.

The Ministry is cognizant of the demands that were placed on your company by the Chief Inspector's Orders of August 18, 2014, and does not wish to place any additional undue burdens on your company. However, the previous Orders were issued before the mechanism of failure was known. Consequently, you are asked to provide a letter of assurance to respond to the items listed above. The letter is to be prepared and sealed by a qualified professional engineer, and is to be submitted to the Chief Inspector of Mines by June 30, 2015. To facilitate MEM's review, you are asked to maintain the above numbering system in your response to each item.

It is envisioned that the above items would best be addressed through a fulsome review of existing information. Where this information has not been compiled, it will be necessary to conduct a review of historical information to determine if any gaps remain in the understanding of the relevant conditions for the tailings storage facility dams on your site. Where appropriate, follow-up actions shall be identified that will be taken to address any opportunities for improvement.

Documents supporting the letter of assurance shall be maintained on-site and shall be made available to any Inspector of Mines upon request.

It should be noted that the Panel made a number of additional recommendations in Chapters 9 and 11 of their January 30, 2015 *Report on Mount Polley Tailings Storage Facility Breach.* MEM is in general agreement with all of the recommendations, and will be examining each of them to determine how they can be implemented over the coming weeks and months. You are asked to do the same.

Specifically, in your response, please also provide the following information in order to inform an Action Plan on implementation of other Panel Recommendations:

- Is your mine implementing the "Toward Sustainable Mining" initiative of the Mining Association of Canada? Are there any plans to do so?

- Does your mine have an Independent Tailings Dam Review Board (ITRB) in place? Is one planned?

Thank you for your prompt attention to these matters,

Regards,

Al Hoffman, P. Eng.
Chief Inspector of Mines
Ministry of Energy and Mines

Cc: Diane Howe, Deputy Chief Inspector, Reclamation and Permitting, MEM
George Warnock, Manager, Geotechnical Engineering, MEM
Heather Narynski, Sr. Geotechnical Inspector, MEM

APPENDIX II

Summary of Relevant Reports

Reference	Reviewed Data/ Key Information
Rescan . 1990. "Stage 1 Addendum Report", April 1990.	• Drill hole logs and hydraulic conductivity testing data. • Note: only a plan of the site and the 1988 SRK drillhole logs (reproduced as an appendix) from this report were found.
Klohn Crippen (KC) 1994a. "QR Gold Project Tailings Impoundment and Fresh Water Pond Final Design of Operating Facilities", August 1994.	• Final design, design basis and supporting site investigation conducted for the QR Tailings Facility. • Surficial geology, 1994 test pit logs, laboratory testing data (PSDs, permeability testing, Atterberg limits), design drawings, seismic assessment criteria and slope stability analyses were used in this review.
Klohn Crippen (KC) 1994b. "QR Gold Project Tailings Impoundment and Fresh Water Pond Technical Specifications for Construction", August 1994.	• Technical specifications, tender drawings and technical information for the construction of the QR TSF. • Design particle size distributions for construction materials, 1994 test pit logs (KC), 1988 test pit logs (SRK), and design drawings (including inferred geologic sections).

Klohn Crippen (KC) 1995a. "QR Gold Project Tailings Impoundment and Fresh Water Pond Stage 1 As-Built Report", February 1995.	• Construction details and quality assurance conducted for the Tailings Dam and the Cross-Dyke for the period of September 1994 to January 1995, including:
	  • Dam foundation material.
	  • Foundation preparation.
	  • Fill placement and compaction.
	  • Design changes.
	  • Particle size distributions for as-built dam zones.

Klohn Crippen (KC) 1995b. "Tailings Dam Re-Design Report", June 1995.	• Redesign of the tailings dam for a maximum crest elevation of 1027 m to allow low grade ore and PAG waste rock to be permanently stored within the tailings impoundment.
	  • Design gradations for fine and coarse filter zones.
	  • Seepage and stability analyses.

Klohn Crippen (KC) 1996. "Tailings Facilities - 1995 Annual Review and As-Built Report", April 1996.	• Construction details and quality assurance conducted for the Tailings Dam for the period of September 1994 to January 1995, including:
	  o Dam foundation material.
	  o Foundation preparation.
	  o Fill placement and compaction.
	  o Design changes.
	  o Particle size distributions for as-built dam zones.

Klohn Crippen (KC) 1997. "QR Project - Tailings Impoundment and Freshwater Pond 1996 Annual Review and As-Built Report", June 1997.	• Overview of the construction, operation and performance of the QR tailings facility for the period of November 1, 1995 to October 31, 1996.
	• The annual review indicates that no evidence of instability cracking or unusual settlements in the tailings dam.
	• Construction details and quality assurance conducted for the Tailings Dam for the period of November 1995 to June, 1996, including:
	  o Dam foundation material.
	  o Foundation preparation.
	  o Fill placement and compaction.
	  o Design changes.
	  o Particle size distributions for as-built dam zones.
	  o The report indicates that some of the filter placement was monitored by Kinross and subsequently, verified by KC with two test pits advanced in the filter zone.

Klohn Crippen (KC) 1997. " QR Project Tailings Facility - 1997 Raise of Cross-Dyke" (Letter), May 1997.	• Outlines instructions for the construction and monitoring of the 1997 Cross Dyke raise. Monitoring of the construction by Kinross is noted as acceptable because the Cross-dyke was understood to be a temporary structure, to be decommissioned in 1998, at the time. • Letter indicates water levels in the (now decommissioned) fresh water pond are higher than the tailings pond and the lift was therefore designed for flow from the south towards the north through the Cross-Dyke.

Reference	Reviewed Data/ Key Information
Klohn Crippen (KC) 1997. "Tailings Dam and Fresh Water Dam Re-Design Report", June 1997.	• Summarizes a revised recommended procedure for the raise of the Cross-Dyke and a re-design for the Cross-Dyke. • Indicates movement in the west high wall of the Main Zone Pit necessitated re-evaluation of the Fresh Water Dam as a closure structure, and the resulting re-design of the Cross-Dyke for use as a closure structure.

Klohn Crippen (KC) 1998. "QR Project Tailings Facility - 1998 Construction Activities", August 1998.	• Outlines construction activities and quality assurance measures undertaken at the Cross-Dyke in June, 1998, including:
	  • As-built sections within the dam.
	  • Particle size distributions of placed materials.
	  • Select information on design gradations of construction material.l
	  • Fill placement and compaction.
	  • Design changes.
	  • The report notes a zone of fill placement below the crest of the Cross-Dyke with compaction below the specified minimum compaction rates.

Klohn Crippen (KC) 1998. "Water Management Plan for Temporary and Permanent Closure", May 1998.	• Summary of temporary and permanent water management plans for the QR mine TSF and open pits.
Klohn Crippen (KC) 2000. "QR Project - Tailings Impoundment and Freshwater Pond 1999 Annual Review", March 2000.	• Summary of observations and review of operational performance of the QR Tailings facility from November 1, 1998 - October 31, 1999. • The report addresses BC ministry concerns regarding the less compacted fill zone noted in the 1998 construction report. Future raises of the Cross-Dyke are designed for a downstream construction method, with a low permeability core keyed into the downstream slope of the Cross-Dyke to minimize the potential impact of a zone of low compaction. • First mention of a broken pipe in the east half of the seepage collection ditch requiring repair, erosion of the west abutment of the Cross-Dyke.

Klohn Crippen (KC) 2001. "QR Mine Tailings Facility - Design for Permanent Closure Final Report", July 2001.	• Summary of the redesign of the cross-dyke to an elevation of 1025 and change in spillway channels.
	  • General notes on seepage and stability.
	  • Construction specifications for particle size distributions.

Klohn Crippen (KC) 2002. "QR Project – Tailings Impoundment and Freshwater Pond 2000 / 2001 Review", May, 2002. DRAFT.	• Summary of observations and review of operational performance of the QR Tailings Facility from November 1, 1999 to October 31, 2001. • No major deficiencies are noted.

Klohn Crippen Berger (KCB) 2003. "QR Mine 2002 Permanent Closure Construction Summary" March 2003.	• Summary of construction observed and quality assurance undertaken for the construction of works for the Cross-Dyke and the Cross Dyke in 2002, including:
	  • Dam foundation material.
	  • Foundation preparation.
	  • Fill placement and compaction.
	  • Design changes.
	  • Particle size distributions for as-built dam zones.
	  • Includes records of the deconstruction of the Fresh Water Dam.

Klohn Crippen Berger (KCB) 2006. "QR Mine 2006 Technical Specifications - Tailings Dam and Cross Dyke", July 2006.	• Outlines the required construction scope and specification for the next phase of construction, including: • Design particle size distributions.

Klohn Crippen Berger (KCB) 2006. "QR Mine - Tailings Dam and Cross Dyke Re-Design Report", May 2006.	• Outlines the redesign of the tailings dam and cross dyke to elevations of 1031 m
	  • Design particle size distributions.
	  • Design cross-sections of the dam.
	  • Seepage and stability analyses of the proposed structures.

Klohn Crippen Berger (KCB) 2008. "QR	• Summary of observations and review of operational performance of the QR

Reference	Reviewed Data/ Key Information
Mine - Tailings Impoundment and Surface Water Management Structures 2007 Annual Geotechnical Review", August 2008.	Tailings facility in 2007. • The first noted reference to a gradual increase in water levels from 2001 to 2008 in TDP95-8, located in the Tailings Dam. • Progressive increases in water levels are noted for the Cross-Dyke, believed to be in response to the filling of the impoundment with water.

Klohn Crippen Berger (KCB) 2009. "QR Mine - 2007 Construction Summary Report", May 2009.	• Outlines the construction conducted in 2007 for the tailings dam and the Cross Dyke
	  • As-built dam fill zones.
	  • Particle size distribution.
	  • General construction detail.s
	  • Design specifications and modifications including gradations of till materials used in the construction of the dams and fill zones for the sandy till and clayey till.

Klohn Crippen Berger (KCB) 2009. "QR Mine - Tailings Impoundment and Surface Water Management Structures 2008 Annual Geotechnical Review", February 2009.	• Summary of observations and review of operational performance of the QR Tailings facility in 2008. • A review of cross dyke stability and threshold levels is recommended to be conducted as soon as possible.
Klohn Crippen Berger (KCB) 2010. "QR Mine - Tailings Impoundment and Surface Water Management Structures 2009 Annual Geotechnical Review", March 2010.	• Summary of observations and review of operational performance of the QR Tailings facility in 2009. • Review findings and recommendations are generally similar to previous years.

Klohn Crippen Berger (KCB) 2011. "QR Mine - Tailings Impoundment and Surface Water Management Structures, 2010 Annual Geotechnical Review", March 2011.	• Tailings and water management plan for continued operation of the QR mine.
	  • Phreatic surfaces within the two dams are noted as increasing, although below threshold warning levels. No signs of instability are noted.
	  • A review of the stability of the Cross-Dyke is recommended. The report notes that a dam safety review has never been done and is recommended.

Klohn Crippen Berger (KCB) 2012. "QR Mine Water Balance for Potential Tailings Deposition Scenarios", August 2012.	• Evaluation of options to retain a water cover during closure, including information pertaining to previous water balances:
	  • Runoff coefficients.
	  • Catchment delineations.
	  • Precipitation data.

Klohn Crippen Berger (KCB) 2012. "Tailings Storage Facility 2011 Tailings Dam Seepage Assessment", January 2012.	• Outlines the site investigation conducted at the QR Tailings Dam to assess dam foundation and bedrock conditions pertaining to excess seepage from the Tailings Dam.
	  • Drillhole data.
	  • Dam foundation information.

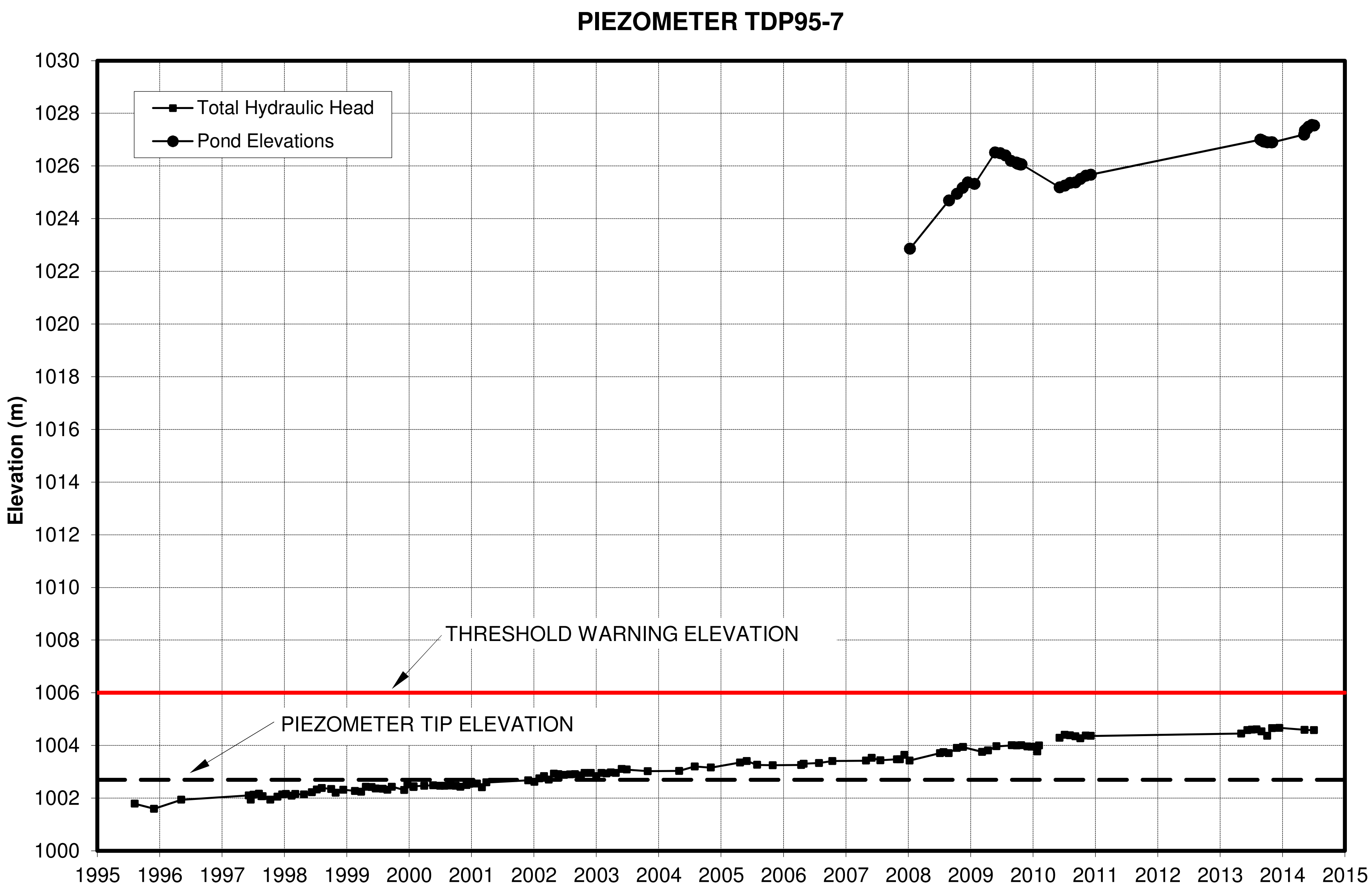
Klohn Crippen Berger (KCB) 2014. "QR Mine Tailings Storage Facility Interim Status Construction Summary - Rev 1", May 2014.	• Outlines the construction works conducted in 2012 and 2013, including QA data for:
	  • As-built dam zones.
	  • Particle size distribution of fill materials.
	  • General construction notes.

Klohn Crippen Berger (KCB) 2014. "QR Mine 2012 TSF Phase II Seepage Assessment Report on Site Investigation and Trial Grouting Program – Draft", March 2014.	• Summary of the trial grouting program. • Drill hole data.

Reference	Reviewed Data/ Key Information
Klohn Crippen Berger (KCB) 2014. QR Mine Tailings Storage Facility Trial Grouting Program – Draft, March 2014.	• Summary of the work conducted for the grouting trial, the results of the grouting trial, and the work remaining for this scope of work.
Klohn Crippen Berger (KCB) 2014. "QR Mine Tailings Storage facility - Tailings Storage Facility 2014 Dam Safety Inspection Report - Rev 3", Novemeber 2014	• Summary of observations and review of operational performance of the QR Tailings facility in 2014Summary of most recent recommendations and any deficiencies identified for the QR TSF.
Klohn Crippen Berger (KCB) 2014. "QR Mine Tailings Storage Facility, 2014 Construction Summary Report", Novemeber 2014.	• Outlines the construction works conducted in 2014, including: • Spillway design and construction modifications.

APPENDIX III

2014 Piezometer Readings


PIEZOMETER TDP95-7
Total Hydraulic Head
Pond Elevations
Elevation (m)
THRESHOLD WARNING ELEVATION
PIEZOMETER TIP ELEVATION
1030
1028
1026
1024
1022
1020
1018
1016
1014
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1010
1008
1006
1004
1002
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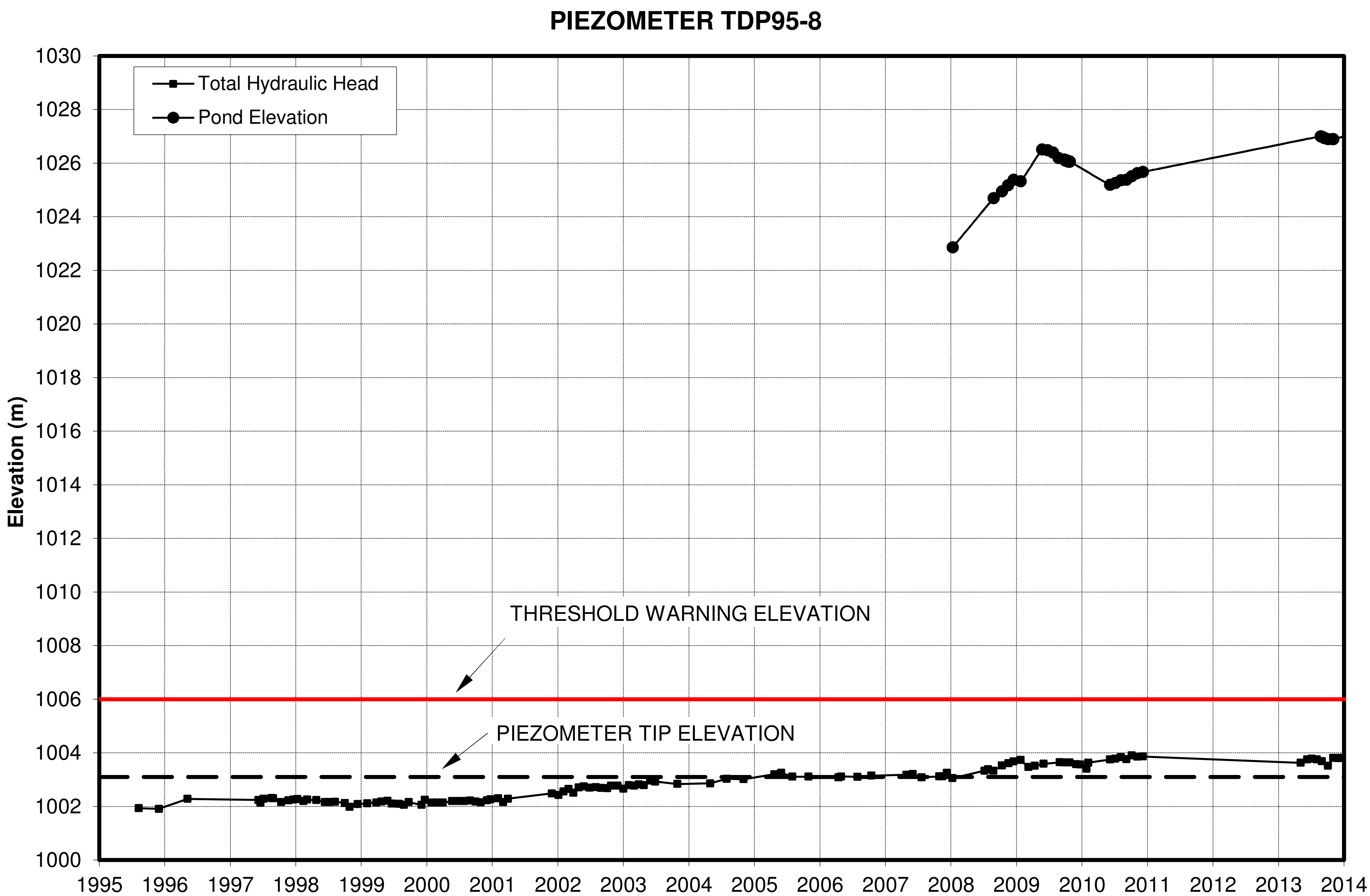
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015


PIEZOMETER TDP95-8
Total Hydraulic Head
Pond Elevation
Elevation (m)
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1010
1008
1006
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1002
1000
THRESHOLD WARNING ELEVATION
PIEZOMETER TIP ELEVATION
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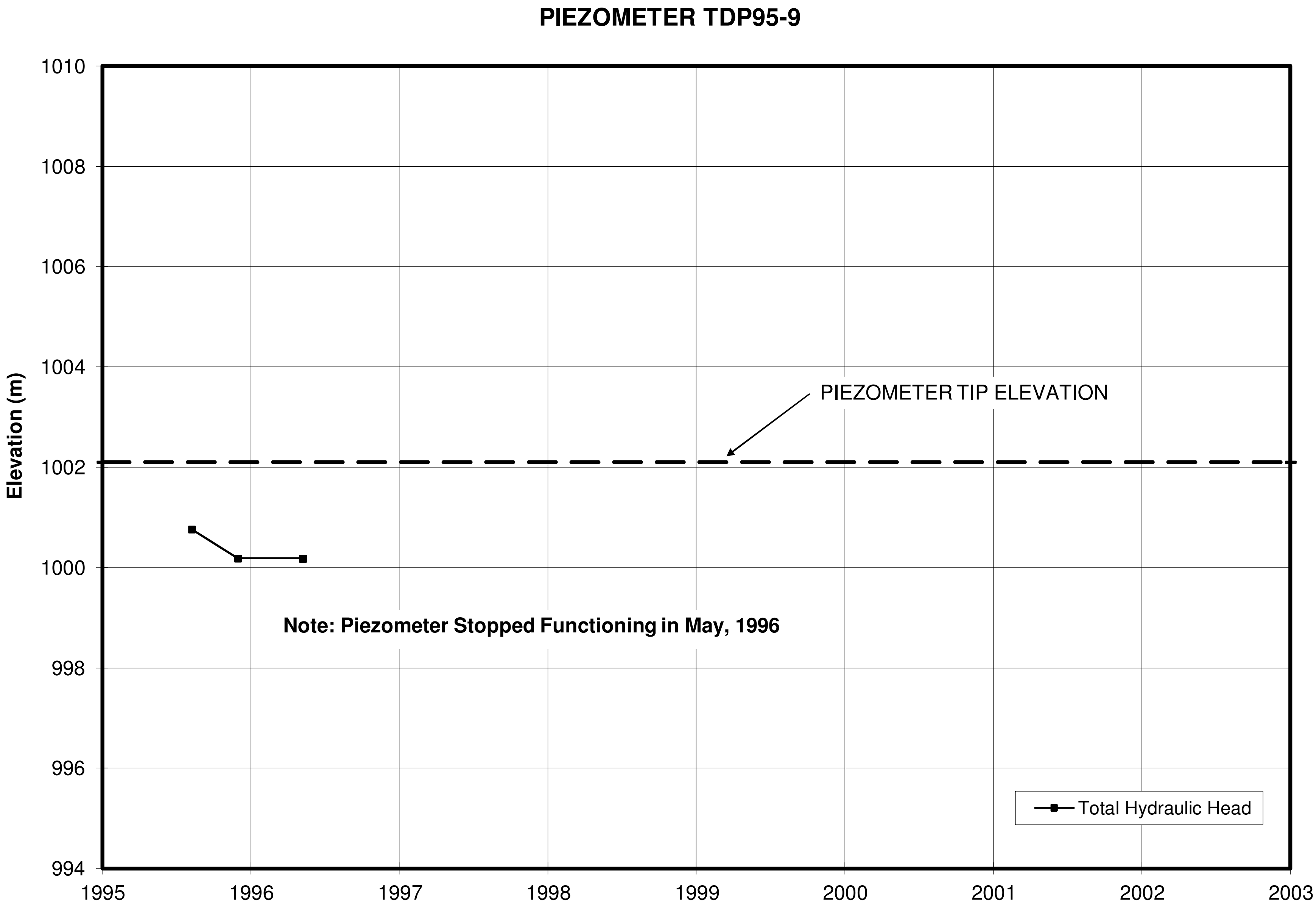
2011
2012
2013
2014


PIEZOMETER TDP95-9
Elevation (m)
1010
1008
1006
1004
1002
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998
996
994
1995
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1997
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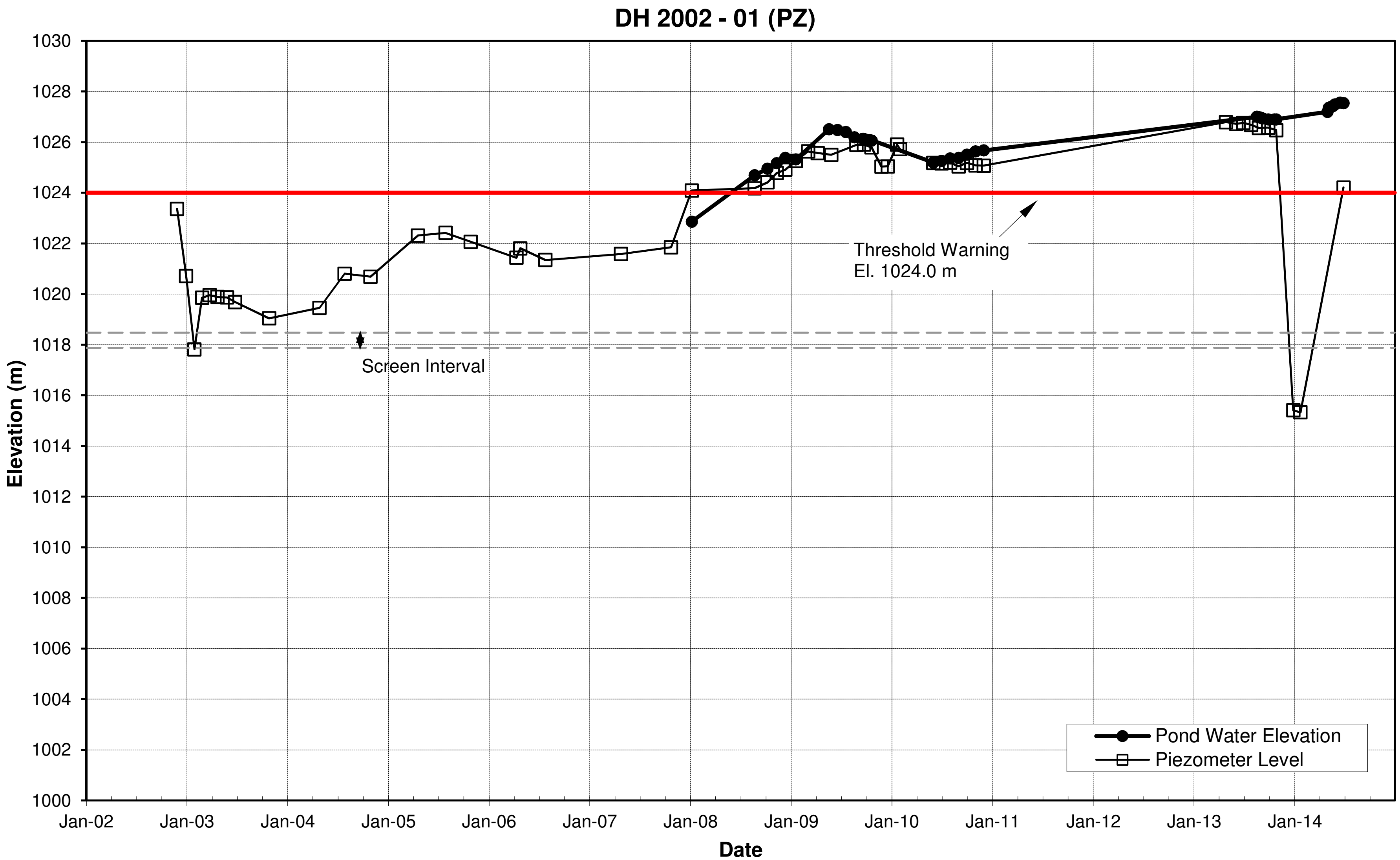
2001
2002
2003
PIEZOMETER TIP ELEVATION
Note: Piezometer Stopped Functioning in May, 1996
Total Hydraulic Head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Elevation (m)
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1004
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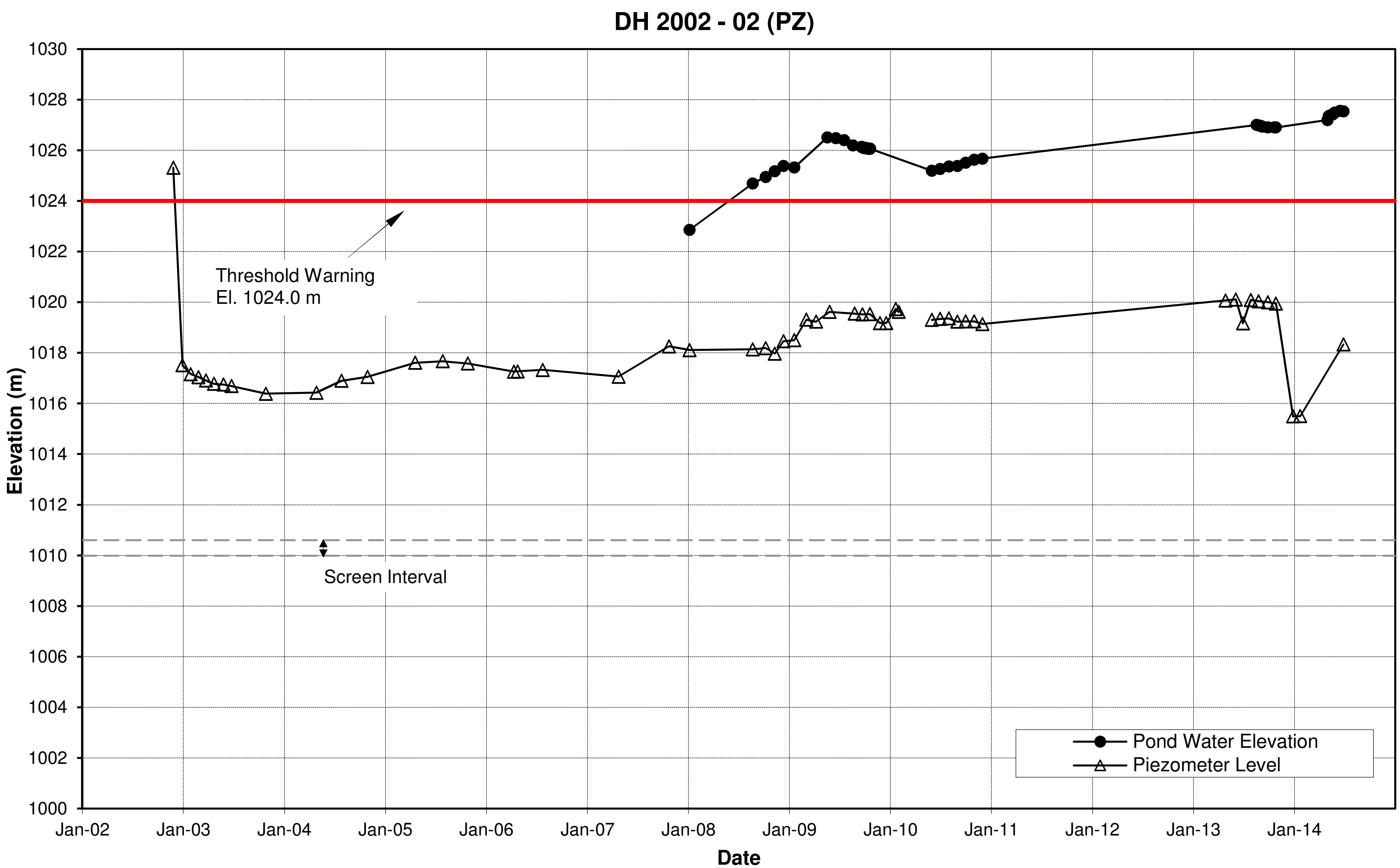
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Date
Threshold Warning
El. 1024.0 m
Screen Interval
Pond Water Elevation
Piezometer Level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1002
1000
Elevation (m)
Threshold Warning
El. 1024.0 m
Screen Interval
Pond Water Elevation
Piezometer Level
Jan-02
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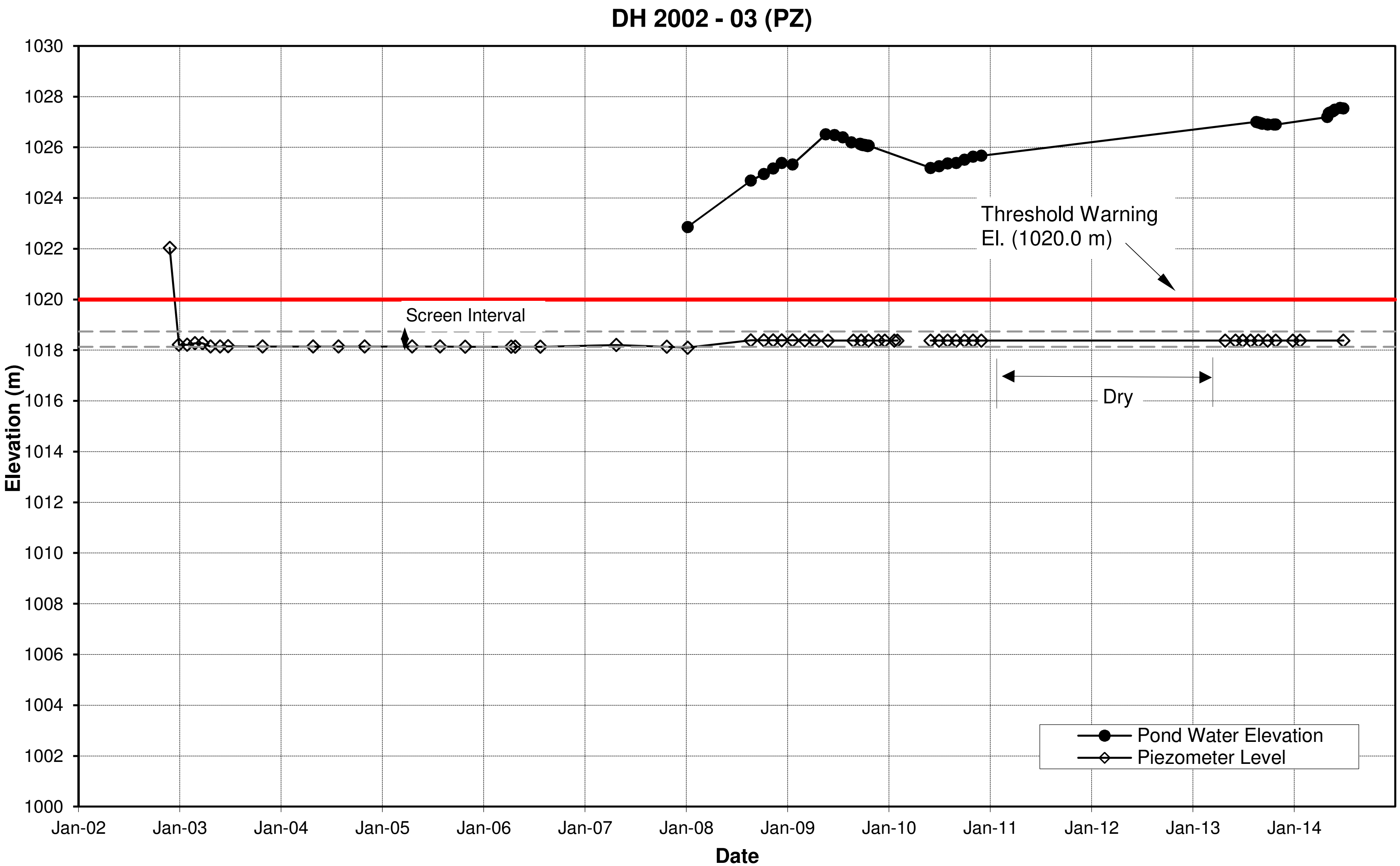
Jan-14
Date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Elevation (m)
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1006
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1002
1000
Jan-02
Jan-03
Jan-04
Jan-05
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Jan-07
Jan-08
Jan-09
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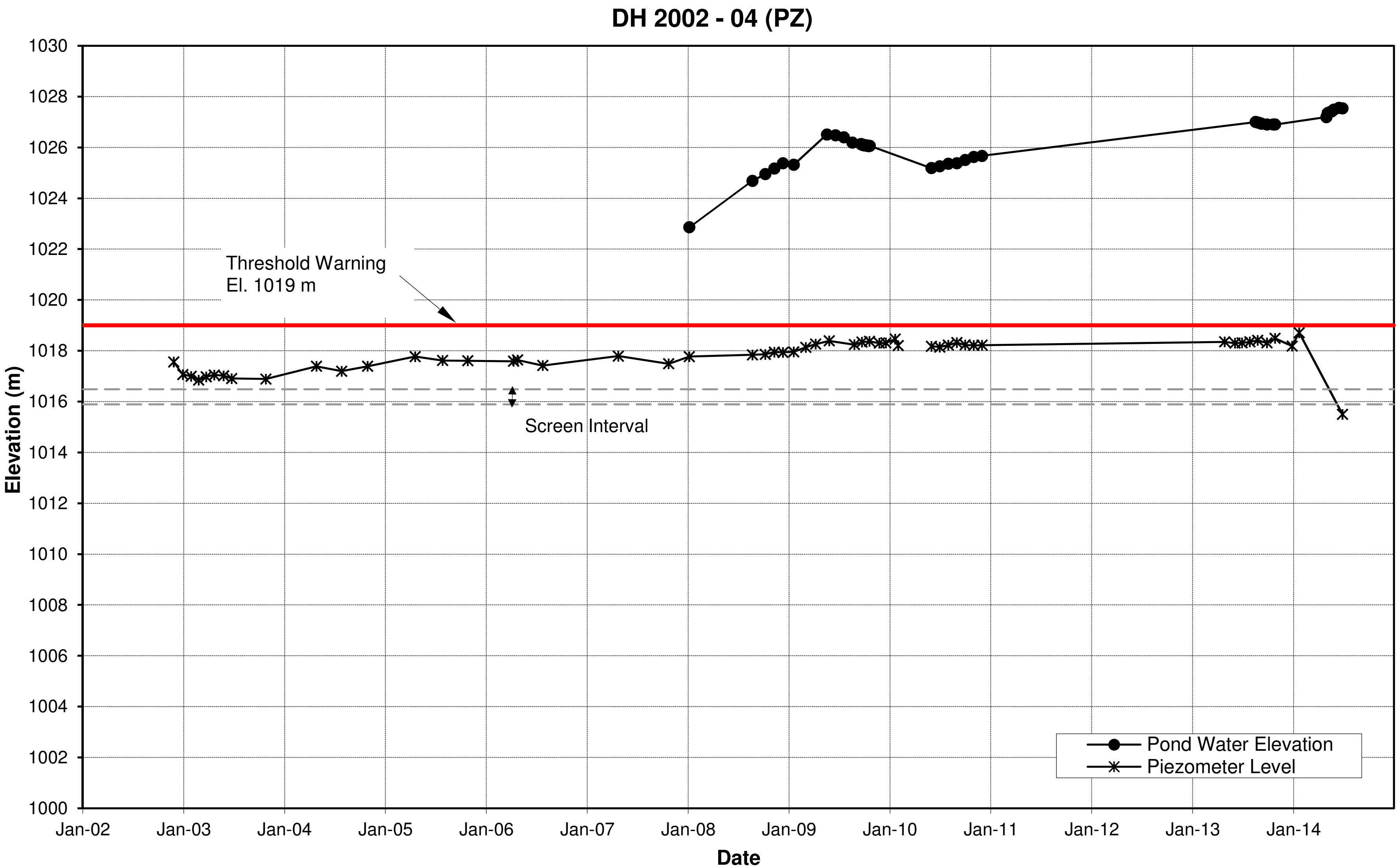
Threshold Warning
El. (1020.0 m)
Screen Interval
Dry
Pond Water Elevation
Piezometer Level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Elevation (m)
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1004
1002
1000
Threshold Warning
El. 1019 m
Screen Interval
Pond Water Elevation
Piezometer Level
Jan-02
Jan-03
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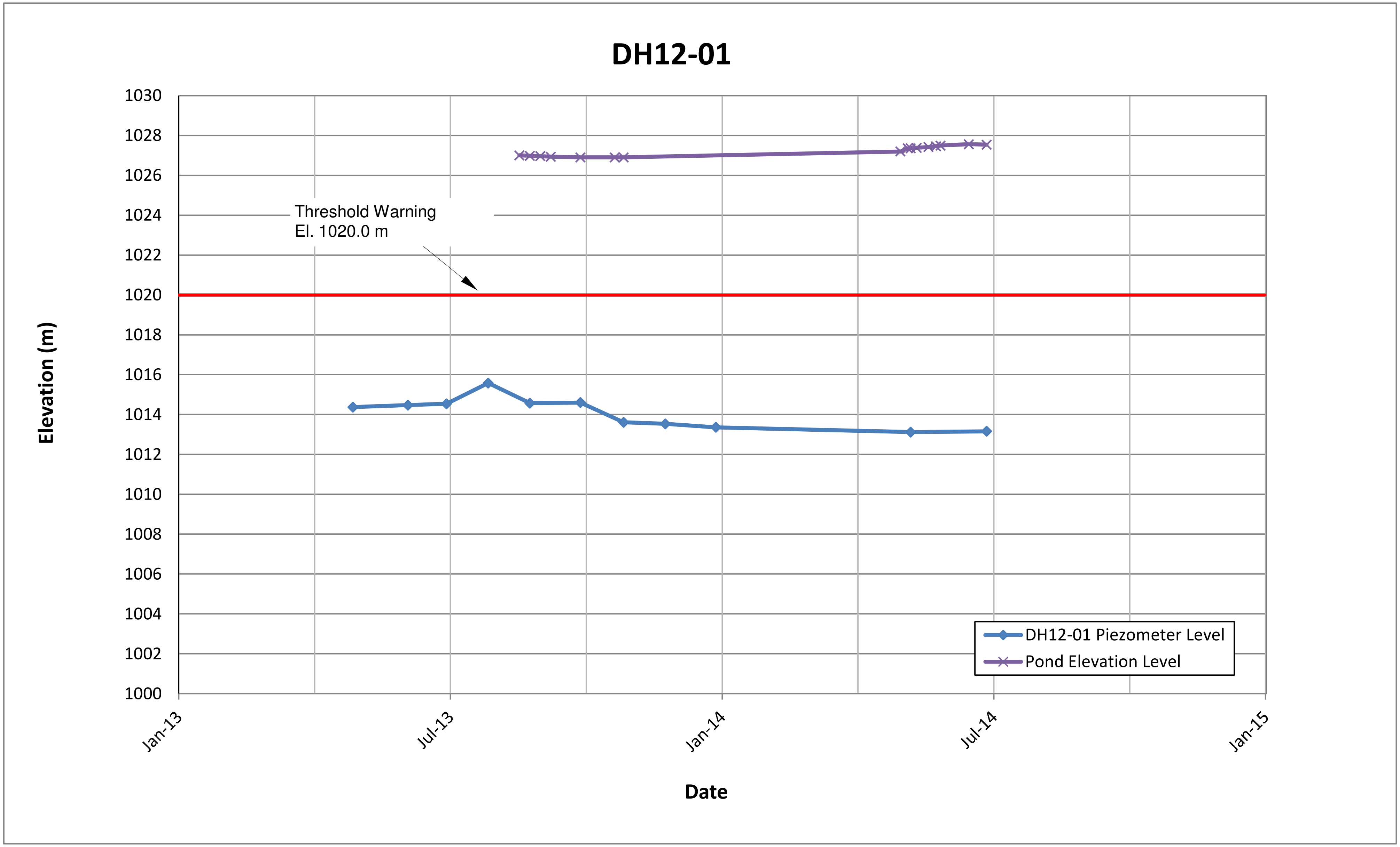
Jan-14
Date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Elevation (m)
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1002
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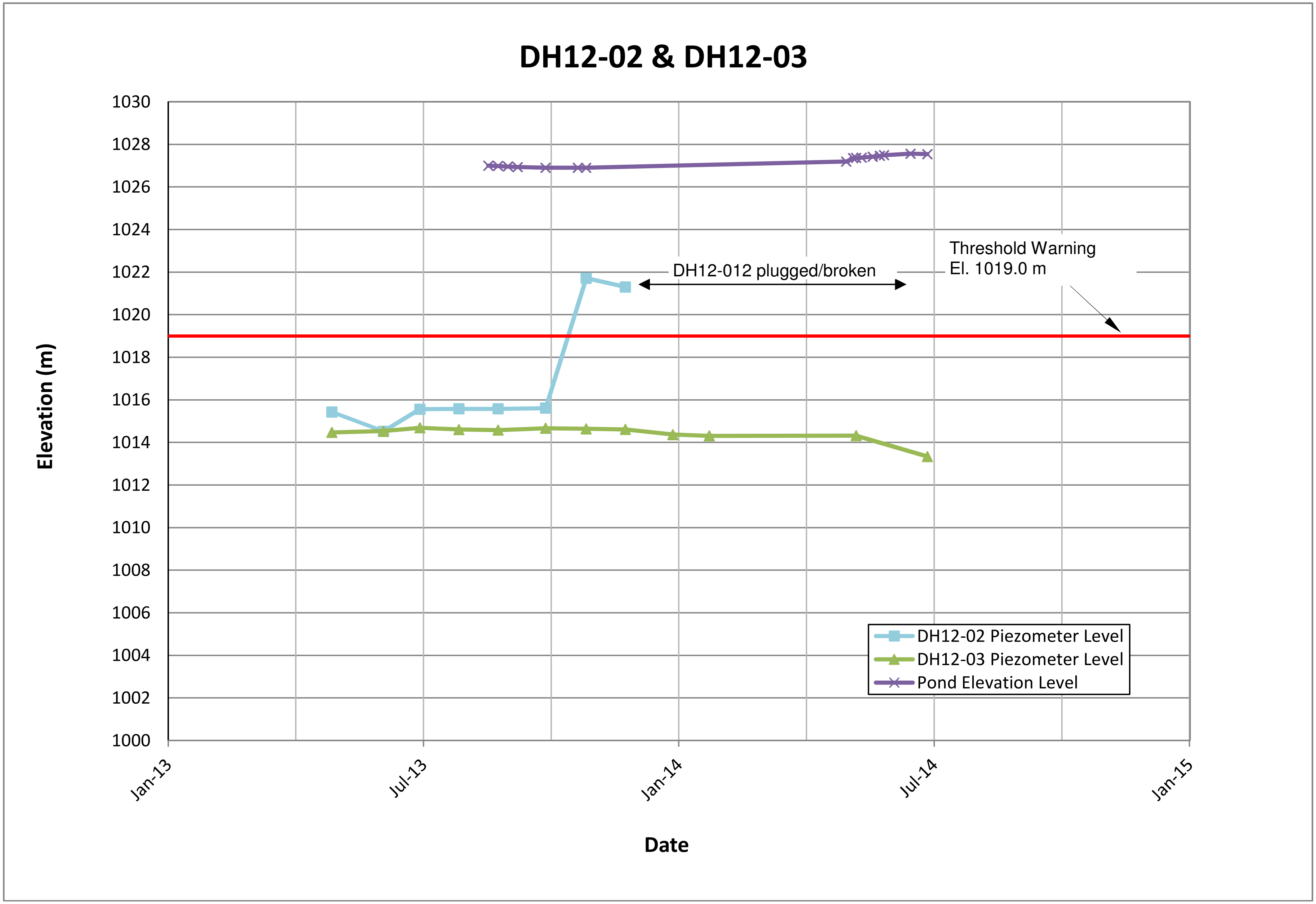
Date
DH12-01 Piezometer Level
Pond Elevation Level


DH12-02 & DH12-03
Elevation (m)
1030
1028
1026
1024
1022
1020
1018
1016
1014
1012
1010
1008
1006
1004
1002
1000
Jan-13
Jul-13
Jan-14
Jul-14
Jan-15
Date
DH12-012 plugged/broken
Threshold Warning
El. 1019.0 m
DH12-02 Piezometer Level
DH12-03 Piezometer Level
Pond Elevation Level

APPENDIX IV

2014 Site Photos

Appendix IV
Inspection Photos

Photo I-1 Cross Dyke Overview (looking West)

Photo I-2 Cross Dyke: Toe Ditch from Right Abutment to French Drain.

Photo I-3 Cross Dyke: Upstream Slope, Armouring incomplete at the time of site visit.

Photo I-4 Tailings Beach on West Side of Impoundment. Heavy vegetation on slope above beach.

Photo I-5 Pumphouse in impoundment currently active supplying water to mill.

Photo I-6 Cross Dyke: Upstream Face in area where armouring is complete.

Photo I-7 **Cross Dyke Downstream Face. Seepage face observed partway down slope during DSI site visit has since dried.**

Photo I-8 **Cross Dyke: Fine Filter Blanket Drain overbuilt, but can been remediated since site visit.**

Photo I-9 North Dam Overview (looking East)

Photo I-10 North Dam Downstream Face. Appears oversteepened. Slope will be confirmed with as-constructed survey.

Photo I-11 **North Dam Crest. Right abutment material was loose and uncompacted at time of site visit. Has since been remediated.**

Photo I-12 **North Dam Overview (looking West)**

Photo I-13 North Dam Upstream Face, Armouring incomplete at time of site visit

Photo I-14 North Dam Bench below Crest

Photo I-15 North Dam Seepage Return pipe leaking at Upper Bench.

Photo I-16 North Dam downstream rockfill face and seepage collection pond.

Photo I-17 North Dam Toe. Seepage weir functions but should be kept clear of debris.

Photo I-18 North Dam Toe east weir. Flow ~ 10 L/s.

Photo I-19 North Dam Rock Drain Outlet (Flow ~ 8 L/s)

Photo I-20 Seepage Collection Pond (toe of North Dam). Note rockfill slope appears oversteepened.

Photo I-21 **East Diversion Ditch. Overgrown but generally clear of major debris. Channel dry at the time of the site visit.**

Photo I-22 **West Diversion Ditch. Clear with some indications of recent flow.**

APPENDIX V

Design Filter Assessment

Appendix V
Comparison of Design Gradations to Modern Criteria

I-1 ASSESSMENT OF DESIGNED FILTER ZONES

The design of the assessed filter zones were completed as follows. Available design information is summarized as follows.

Table 1.1 Available Design Information for Zones Assessed for Filter Compatibility in the North Dam

Dam	Year of Design or Re-Design	Description of Fine Filter Specifications	Description of Coarse Filter Specification	Description of Core Specifications
North Dam	1994	Design envelope specified.	Maximum particle size specified.	Design envelope specified.
North Dam	1995	New design envelope specified.	Design envelope specified.	As specified in 1994.
North Dam	1997	As specified in 1995.	As specified in 1995.	As specified in 1994.

Table 1.2 Available Design Information for Zones Assessed for Filter Compatibility in the Cross Dyke

Dam	Year of Design or Re-Design	Description of Fine Filter Toe Drain Specifications	Description of Core Specifications	Description of Downstream Shell Specifications
Cross Dyke	1994	--	Design envelope specified per North Dam.	--
Cross Dyke	2001	Specifications per 1995 Fine Filter specifications for North Dam.	As specified in 1997 specifications for North Dam.	Minimum % passing the No. 4 sieve and a maximum % passing the No. 200 sieve specified.
Cross Dyke	2006	Minor changes to Fine Limit of Gradation Envelope.	Fines content (<0.075 mm) specified.	Design envelope specified.

Table 1.3 Assessment of the Filter Design According to the USACE (2004) Criteria – North Dam

Year(1)			Filter Design (2)					USACE Criteria (3)					Comparison of Design to Criteria				
	Base Soil	Filter	% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)	% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)	% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)
1994	Till Core	Fine Filter	5	1.5	0.2	48	75	<5	<0.7	>0.1	<20	<75	Pass	Fail	Pass	Fail	Pass
	Fine Filter	Coarse Filter	Coarse filter specified as 150 mm minus rockfill.					<5	<18	>1.2	25	<75	--	--	--	--	--
1995	Till Core(4)	Fine Filter	5	3	0.4	55	75	<5	<0.7	>0.1	<20	<75	Pass	Fail	Pass	Fail	Pass
	Fine Filter	Coarse Filter	--	27	3	173	203	<5	<15	>2.1	<30	<75	--	Fail	Pass	Fail	Fail

(1) The year corresponds to the date of the specifications.
(2) The design columns pertain to the filter lift that protects the core constructed in the year noted in the first column. Design gradations for the filter zone are presented. Parameter values correspond with values along the coarse limit of the specified design envelope with the exception of the minimum D15 (USACE, 2004) criteria, which was obtained from the fine limit of the specified design envelope.
(3) USACE (2004) criteria were calculated based on the finest gradation of the protected material, after regarding to a maximum grain size of 4.75 mm.
(4) Only filter gradations were modified in 1995. 1995 Re-design of filters were compared to the 1994 construction specifications for the till core.

Table 1.4 Assessment of the Filter Design to the Kenney and Lau (1986) Criteria for Susceptibility to Internal Erosion – North Dam

Year(1)	Zone	Filter Design	Kenney and Lau Criteria(2)	Comparison of Design to Criteria
1994	Fine Filter	H>F for F=5, 10, 20	H < F for F<20%	Fail
	Coarse Filter	Coarse filter specified as 150 mm minus rockfill.	H < F for F<20%	--
1995	Fine Filter	H=19 – 41 For F=5 – 30	H < F for F<20%	Fail
	Coarse Filter	H=53 – 56 For F = 5 - 30	H < F for F<20%	Fail

(1) The year corresponds to the date of the specifications.
(2) Kenney and Lau (1986) method was applied for a widely graded filter. Parameter H corresponds to the mass fraction of the filter particles whose diameter ranges between D and 4D. F corresponds to the mass fraction of particles whose diameter is smaller than diameter D.

Table 1.5 Assessment of the Filter Design According to the USACE (2004) Criteria – Cross Dyke

Year[1]			Filter Design [2]					USACE Criteria [3]					Comparison of Design to Criteria				
	Base Soil	Filter	% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)	% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)	% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)
2001	Till Core[4]	Fine Filter Toe Drain	5	3	0.4	55	75	<5	<0.7	>0.1	<20	<75	Pass	Fail	Pass	Fail	Pass
2001	Till Foundation [5]	Fine Filter Toe Drain	5	3	0.4	55	75	<5	<0.7	>0.1	<20	<75	Pass	Fail	Pass	Fail	Pass
2001	Down-stream Shell	Fine Filter Toe Drain	Downstream shell specifications consist of a minimum of 50% passing the No. 4 sieve and a maximum of 30% by weight passing the No. 200 sieve.					--	--	--	--	--	--	--	--	--	--
2006	Down-stream Shell	Fine Filter Toe Drain	5	3	0.4	55	75	<5	<9.6	>0.3	<20	<75	Pass	Pass	Pass	Fail	Pass

(1) The year corresponds to the date of the specifications.
(2) The design columns pertain to the filter lift that protects the core constructed in the year noted in the first column. Design gradations for the filter zone are presented. Parameter values correspond with values along the coarse limit of the specified design envelope with the exception of the minimum D15 (USACE, 2004) criteria, which was obtained from the fine limit of the specified design envelope.
(3) USACE (2004) criteria were calculated based on the finest gradation of the protected material, after regarding to a maximum grain size of 4.75 mm.
(4) Although the fine filter toe drain specification was produced in 2001, the design of the till core is based on the 1994 construction specifications.
(5) Till foundation gradation based on the gradation of basal clay sample from TP94-17 at a depth of 3.3 m (KL, 1994).

Table 1.6 Assessment of the Filter Design to the Kenney and Lau (1986) Criteria for Susceptibility to Internal Erosion – Cross Dyke

Year(1)	Zone	As-Built Filter	Kenney and Lau Criteria(2)	Comparison of Design to Criteria
2001	Fine Filter Toe Drain	H>F for F=5, 10, 20	H < F for F<20%	Fail
2006	Fine Filter Toe Drain	H>F for F=5, 10, 20	H < F for F<20%	Fail

(1) The year corresponds to the date of the specifications.
(2) Kenney and Lau (1986) method was applied for a widely graded filter. Parameter H corresponds to the mass fraction of the filter particles whose diameter ranges between D and 4D. F corresponds to the mass fraction of particles whose diameter is smaller than diameter D.

APPENDIX VI

Comparison of As-Built Gradations to Modern Criteria

Appendix VI
Comparison of As-Built Gradations to Modern Criteria

I-1 ASSESSMENT OF AS-BUILT FILTERS FOR THE NORTH DAM

Table 1.1 As-Built Till Core and Fine Filter Compared to Foster and Fell (2001) – North Dam

Year	Crest Elevation	Till Core			Fine Filter	Comparison of As-Built to Criteria[2] (Till / Fine Filter) (Foster and Fell, 2001)		
		D100 (mm)	d85[1] (mm)	Finer than 75 µm (%)	D15 (mm)	No Erosion	Excessive Erosion	Continuing Erosion
1994	1009	76	2-3	25-37	Filter constructed in 1995	Fail	Pass	Pass
1995	1013 (Phase I)	101	3-4	19	0.9-6	Pass	Pass	Pass
1996	1020	76	0.7-2	48-60	0.6-2	Fail	Pass	Pass
1997	1023	No as-built information available.			No as-built information available.	--	--	--
2002	1025.0 (west end of dam)	No as-built information available.			No filter construction undertaken in 2002.	--	--	--

[1] d85 (mm) is based on the particle size gradation after regrading to a maximum grain size of 4.75 mm.
[2] Application of the Foster and Fell criteria may not be applicable as both the filter and base soil are susceptible to segregation (as per USACE, 2004) and internal instability (as per Kenney and Lau, 1986).

Table 1.2 As-Built Coarse Filter and Fine Filter Compared to Foster and Fell (2001) – North Dam

Year	Crest Elevation	Fine Filter			Coarse Filter	Comparison of As-Built to Criteria[2] (Fine Filter / Coarse Filter) (Foster and Fell, 2001)		
		D100 (mm)	d85[1] (mm)	Finer than 75 µm (%)	D15 (mm)	No Erosion	Excessive Erosion	Continuing Erosion
1994	1009	Filter constructed in 1995			Filter constructed in 1995	--	--	--
1995	1013 (Phase I)	76	3-4	19-21	4-25	Fail	Pass	Pass
1996	1020	76	4	24	No as-built information available.	--	--	--
1997	1023	No as-built information available.			No filter construction undertaken in 2002.	--	--	--
2002	1025.0 (west end of dam)	No filter construction undertaken in 2002.			No filter construction undertaken in 2002.	--	--	--

[1] d85 (mm) is based on the particle size gradation after regrading to a maximum grain size of 4.75 mm.
[2] Application of the Foster and Fell criteria may not be applicable as both the filter and base soil are susceptible to segregation (as per USACE, 2004) and internal instability (as per Kenney and Lau, 1986).

Table 1.3 Assessment of the Fine Filters According to the USACE (2004) Criteria for Protection of the Till Core

Year[1]	As-Built Filter [2]					Modern Criteria [3]					Comparison of As-Built to Criteria				
	% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)	% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)	% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)
1994	Filter constructed in 1995.					5	<8.6	>0.2	<20	<75	Pass	Pass	Pass	Fail	Pass
1995	3-6%	5.6	0.9	62	75	5	<13.5	>0.5	<20	<75	Pass	Pass	Pass	Fail	Pass
1996	6-8%	1.5	0.6	64	75	5	<0.7	>0.1	<20	<75	Pass[4]	Fail	Pass	Fail	Pass
1997	No as-built information available.					--	--	--	--	--	--	--	--	--	--
2002	No filter construction undertaken in 2002.					--	--	--	--	--	--	--	--	--	--

[1] The year corresponds to the year that the till core lift was constructed.
[2] The as-built columns pertain to the filter lift that protects the core constructed in the year noted in the first column. As-built information is based on the coarsest gradation of the filter material, with the exception of the % passing the No. 200 sieve which shows the range in the available gradations, and the minimum D15 criteria, which shows the finest D15 of the available gradation curves.
[3] USACE (2004) criteria were calculated based on the finest gradation of the protected material, after regarding to a maximum grain size of 4.75 mm.
[4] Although the exact value is outside of the specified criteria, this parameter value for the as-built filter is reasonably near the acceptable modern criteria.

Table 1.4 Assessment of the Coarse Filters According to the USACE (2004) Criteria for Protection of the Fine Filter

Year[1]	As-Built Filter [2]					Modern Criteria [3]					Comparison of As-Built to Criteria				
	% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)	% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)	% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)
1994	Filter constructed in 1995.					--	--	--	--	--	--	--	--	--	--
1995	<5	25	4	180	203	5	<18	>4	<30	<75	Pass	Fail	Pass	Fail	Fail
1996	No as-built information available.					--	--	--	--	--	--	--	--	--	--
1997	No as-built information available.					--	--	--	--	--	--	--	--	--	--
2002	No filter construction undertaken in 2002.					--	--	--	--	--	--	--	--	--	--

(1) The year corresponds to the year that the till core lift was constructed.
(2) The as-built columns pertain to the filter lift that protects the core constructed in the year noted in the first column. As-built information is based on the coarsest gradation of the filter material, with the exception of the % passing the No. 200 sieve which shows the range in the available gradations, and the minimum D15 criteria, which shows the finest D15 of the available gradation curves.
(3) USACE (2004) criteria were calculated based on the finest gradation of the protected material, after regarding to a maximum grain size of 4.75 mm.

Table 1.5 Assessment of the Fine Filters According to the Kenney and Lau (1986) Criteria for Susceptibility to Internal Erosion

Year	As-Built Filter	Modern Criteria[1]	Comparison of As-Built to Criteria
1994	Filter constructed in 1995.	--	--
1995	H>F for F=20%	H < F for F<20%	Fail
1996	H<F for F<20%	H < F for F<20%	Pass
1997	No as-built information available.	--	--
2002	No filter construction undertaken in 2002.	--	--

[1] Kenney and Lau (1986) method was applied for a widely graded filter. Parameter H corresponds to the mass fraction of the filter particles whose diameter ranges between D and 4D. F corresponds to the mass fraction of particles whose diameter is smaller than diameter D.

Table 1.6 Assessment of the Coarse Filters According to the Kenney and Lau (1986) Criteria for Susceptibility to Internal Erosion

Year	As-Built Filter	Modern Criteria[1]	Comparison of As-Built to Criteria
1994	Filter constructed in 1995.	--	--
1995	H>F for F=10%, F=20%	H < F for F<20%	Fail
1996	No as-built information available.	--	--
1997	No as-built information available.	--	--
2002	No filter construction undertaken in 2002.	--	--

[1] Kenney and Lau (1986) method was applied for a widely graded filter. Parameter H corresponds to the mass fraction of the filter particles whose diameter ranges between D and 4D. F corresponds to the mass fraction of particles whose diameter is smaller than diameter D.

I-2 ASSESSMENT OF AS-BUILT FINE FILTERS FOR THE CROSS DYKE

Table 2.1 As-Built Filter Compatibility of the Toe Drain Compared to Foster and Fell (2001) – Cross Dyke

Year	Crest Elevation	Protected Material	Protected Material			Toe Drain Filter	Comparison of As-Built to Criteria[(2)] (Foster and Fell, 2001)		
			D100 (mm)	d85[(1)] (mm)	Finer than 75 µm (%)	D15 (mm)	No Erosion	Excessive Erosion	Continuing Erosion
1994	1021	Till Core	33	2-3	21-36	Filter constructed in 2002	Fail	Pass	Pass
2002	1022.5	Till Core	76	1-2	54-64	0.6-1.7	Fail	Pass	Pass
2002	1022.5	Till Foundation[(2)]	38	0.9	53	0.6-1.7	Fail	Pass	Pass

(1) d85 (mm) is based on the particle size gradation after regrading to a maximum grain size of 4.75 mm.
(2) Application of the Foster and Fell criteria may not be applicable as both the filter and base soil are susceptible to segregation (as per USACE, 2004) and internal stability (as per Kenney and Lau, 1986).
(3) Till foundation gradation based on the gradation of basal clay sample from TP94-17 at a depth of 3.3 m (KL, 1994).

Table 2.2 As-Built Filter Compatibility of the Blanket Drain Compared to Foster and Fell (2001) – Cross Dyke

Year	Crest Elevation	Protected Material	Protected Material			Blanket Drain[(1)]	Comparison of As-Built to Criteria[(2)] (Foster and Fell, 2001)		
			D100 (mm)	d85[(3)] (mm)	Finer than 75 µm (%)	D15 (mm)	No Erosion	Excessive Erosion	Continuing Erosion
2012-2013	1029.3	Downstream Shell	76	1-3	19-66	2-14	Fail	Fail	Pass
2012-2013	1029.3	Till Foundation[(4)]	38	0.9	53	2-14	Fail	Fail	Pass

(1) 2002 filter criteria check was between the downstream shell and the fine filter toe drain. The 2012-2013 filter criteria check was between the downstream shell and the blanket drain to the downstream.
(2) Application of the Foster and Fell criteria may not be applicable as both the filter and base soil are susceptible to segregation (as per USACE, 2004) and internal stability (as per Kenney and Lau, 1986).
(3) d85 (mm) is based on the particle size gradation after regrading to a maximum grain size of 4.75 mm.
(4) Till foundation gradation based on the gradation of basal clay sample from TP94-17 at a depth of 3.3 m (KL, 1994).

Table 2.3 As-Built Filter Compatibility of the Toe Drain Compared to USACE (2004) – Cross Dyke

Year[1]	Protected Soil	As-Built Filter [2]					Modern Criteria [3]					Comparison of As-Built to Criteria				
		% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)	% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)	% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)
1994	Till Core	3-8	1.7	0.6	18	75	5	<8.1	>0.2	<20	<75	Pass[4]	Pass	Pass	Pass	Pass
2002	Till Core	3-8	1.7	0.6	18	75	5	<1.7	>0.1	<20	<75	Pass[4]	Pass	Pass	Pass	Pass
2002	Till Foundation	3-8	1.7	0.6	18	75	5	<0.7	>0.1	<20	<75	Pass	Fail	Pass	Pass	Pass

(1) The year corresponds to the year that the till core lift and filter were constructed.

(2) The as-built columns pertain to the filter lift that protects the core constructed in the year noted in the first column. As-built information is based on the coarsest gradation of the filter material, with the exception of the % passing the No. 200 sieve which shows the range in the available gradations, and the minimum D15 criteria, which shows the finest D15 of the available gradation curves.

(3) USACE (2004) criteria were calculated based on the finest gradation of the protected material, after regarding to a maximum grain size of 4.75 mm.

(4) Although the percentage passing the no. 200 sieve exceeds the 5%, the finest content was found to be reasonably near the acceptable modern criteria.

(5) Till foundation gradation based on the gradation of basal clay sample from TP94-17 at a depth of 3.3 m (KL, 1994).

Table 2.4 As-Built Filter Compatibility of the Blanket Drain Compared to USACE (2004) – Cross Dyke

Year[1]	Protected Soil	As-Built Filter [2]					Modern Criteria [3]					Comparison of As-Built to Criteria				
		% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)	% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)	% Passing No. 200 Sieve	Max. D15 (mm)	Min. D15 (mm)	Max. D90 (mm)	Max. D100 (mm)
2012-2013	Till Core	No data	14	2.5	76	152	5	<0.7	>0.1	<20	<75	--	Fail	Pass	Fail	Fail
2012-2013	Till Foundation	No data	14	2.5	76	152	5	<0.7	>0.1	<20	<75	Pass	Fail	Pass	Pass	Pass

(1) The year corresponds to the year that the fine filter and toe drain were constructed.
(2) The as-built columns pertain to the filter lift that protects the core constructed in the year noted in the first column. As-built information is based on the coarsest gradation of the filter material, with the exception of the % passing the No. 200 sieve which shows the range in the available gradations, and the minimum D15 criteria, which shows the finest D15 of the available gradation curves.
(3) USACE (2004) criteria were calculated based on the finest gradation of the protected material, after regarding to a maximum grain size of 4.75 mm.
(4) Till foundation gradation based on the gradation of basal clay sample from TP94-17 at a depth of 3.3 m (KL, 1994).

Table 2.5 Assessment of the Fine Filters According to the Kenney and Lau (1986) Criteria for Susceptibility to Internal Erosion

Year	As-Built Filter	Modern Criteria[1]	Comparison of As-Built to Criteria
2002	H<F for F=10	H < F for F<20%	Fail
2012-2013	H>F for F=5 to F=20	H < F for F<20%	Fail

[1]Kenney and Lau (1986) method was applied for a widely graded filter. Parameter H corresponds to the mass fraction of the filter particles whose diameter ranges between D and 4D. F corresponds to the mass fraction of particles whose diameter is smaller than diameter D.